U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-279 449

Operations Manual - Sludge Handling and Conditioning

Culp, Wesner, Culp-Clean Water Consultants, El Dorado Hills, CA

Prepared for

Environmental Protection Agency, Washington, D C

Feb 78

EPA-430-9-78-002

PB 279 449

OPERATIONS MANUAL

SLUDGE HANDLING AND CONDITIONING

by

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Contract No. 68-01-4424

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February, 1978

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER PROGRAM OPERATIONS
WASHINGTON, D.C. 20460

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-430-9-78-002	2.	3. RECIPIENT'S ACCESSION NO. PB279449
4. TITLE AND SUBTITLE "Operations Manual - SLUDGE HANDLING AND CONDITIONING"		5. REPORT DATE February 1978 (date of preparation)
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) William F. Ettlich Daniel J. Hinrichs Thomas S. Lineck		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Culp/Wesner/Culp Clean Water Consultants Box 40 El Dorado Hills, CA 95630		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-01-4424
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency 401 "M" St.,S.W. Washington, D.C. 20460		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The overall objective of the manual is to provide guidance in the proper operation and maintenance of various sludge processing, conditioning and disposal systems at wastewater treatment plants. Emphasis is placed on the establishment of good operational procedures, proper testing, and effective measures and procedures for detection and correction of operational problems.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Wastewater, Waste Treatment, Public Utilities; Inspections, Sewage Treatment: Chemical Conditioning,Gravity Thickening Aerobic Digestion, Thermal Treatment, Centrifugation, Vacuum & Pressure Filtration, Lagoons, Composting, Land Application and Landfill.	Problem solving, Operations, Maintenance, Process Control.	
18. DISTRIBUTION STATEMENT Release Unlimited; [redacted] NTIS	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 355
	20. SECURITY CLASS (This page) Unclassified	22. PRICE A16 - A01

EPA Form 2220-1 (9-73)

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ABSTRACT

This work was initiated with the overall objective of providing an operations manual and guidance to assist in the proper operation and maintenance of various sludge processing, conditioning and disposal systems at wastewater treatment plants. Emphasis is placed on the establishment of good operational procedures, proper testing, and effective measures and procedures for detection and correction of operational problems. The style and format of the manual is tailored to the needs of the user.

The processing and disposal systems presented in the manual include those designed to treat various types of sludge generated from primary, secondary and chemical wastewater treatment processes. All of the principal sludge unit processes and unit operations are included such as sludge thickening, stabilization and conditioning, chemical and heat dewatering, heat drying, and ultimate disposal systems.

Step-by-step operation and maintenance procedures are presented for the various systems. Each section contains explicit instructions on process control procedures for detecting and correcting operational problems. Plant type and size are considered where applicable to operational procedures. Specific guidance and procedures for tailoring and modifying the technical information provided in the manual to individual and special cases is included in useful troubleshooting guides, solutions to design shortcomings, and descriptions of design variations of particular processes.

SECTION 1

INTRODUCTION

This manual is an operation and maintenance guide or reference document for use by operating personnel and other individuals interested in improving the performance of municipal wastewater treatment plants. The primary purpose of the manual is to provide operational and maintenance guidance for various sludge unit processes. A secondary purpose of the manual is its use as a supplemental text for various training courses. Consulting engineers, designers, plant operators, educators, and students will also find the manual a useful source document on operation and maintenance of sludge processes.

The manual was developed as described in Section 2 based on state-of-the-art investigation of published literature, manufacturer's operation and maintenance publications, full scale plant experiences, and experience of individuals.

This work was followed up by visits to actual operating facilities of each type to document actual field experiences and verify procedures outlined in the manual.

The manual was written to be readily usable by plant operating personnel. The manual will also be helpful to those who design facilities and prepare plant operation and maintenance manuals.

SECTION 2

DESCRIPTION OF MANUAL

This manual covers each of the sludge processes as a separate unit process. Each of these process sections is complete within itself and contains the following sub-sections as applicable to the specific unit process.

Process Description
Typical Design Criteria and Performance
Staffing Requirements
Monitoring
Normal Operating Procedures
Control Considerations
Emergency Operating Procedures
Common Design Shortcomings
Troubleshooting Guide
Maintenance Considerations
Safety Considerations
Reference Material

PROCESS DESCRIPTION

This is a brief description of the unit process, the features, design differences between variations of the process, mechanical and process operation, and a description of the sidestreams. This paragraph serves as an introduction to the manual for that unit process.

TYPICAL DESIGN CRITERIA AND PERFORMANCE

This paragraph is designed to give a very brief indication of design parameters important to the unit process and expected results. In most cases, typical ranges are given for various types of sludges. Design factors and performance vary widely, however, the information in this manual is intended to illustrate typical current practice. This information was developed primarily from full scale plant operating experiences.

STAFFING REQUIREMENTS

This paragraph contains recommended labor requirements for operation and maintenance of the unit process. The data in this paragraph does not represent an average of current full scale plant experience, but represents the labor required to actually perform the operation, maintenance, and monitoring at a satisfactory level, generally as outlined in the manual.

It is difficult to accurately estimate unit process labor requirements. The information in this manual will provide general guidance, but should not be accepted as absolute. This information was developed from full scale plant experience where satisfactory operation and maintenance is performed, from estimates based on experience, and from other references. Unless noted otherwise, labor requirements were developed from "Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities", EPA Contract No. 14-12-462, October, 1971, as slightly modified to reflect additional and current experience.

It is inferred and intended that labor requirements be additive, i.e., the total staffing for a complete sludge handling system would be the sum of all unit processes as shown in this manual. This is a simplified approach for estimating purposes only, because in many cases there may be some efficiencies in monitoring, maintenance, and operational functions when a number of unit processes are operated as a system. Therefore, care and judgement must be used in applying the staffing information and, again, it is intended only for general guidance.

MONITORING

The monitoring recommendations were developed from "Estimating Laboratory Needs from Municipal Wastewater Treatment Facilities", EPA-430/9-74-002, June, 1973, and full scale plant experiences. The monitoring requirements and practices will vary widely depending on the exact process, the size of the plant, and the needs of the local facility. The intent of this paragraph is to show requirements for an average facility.

NORMAL OPERATING PROCEDURES

These step-by-step procedures for various operating modes were developed from manufacturer's manuals and from actual full scale plant manuals and operations. The procedures have been simplified to cover the general case and may change slightly for a particular manufacturer's equipment.

CONTROL CONSIDERATIONS

The intent of this paragraph is to describe the pertinent physical and process control considerations and the practical application of these considerations to the unit process. Guidance is provided to aid in tailoring the technical process considerations to individual and special plant cases. This paragraph includes the use of sensory observations. The information in this paragraph was developed from technical reference materials and from actual plant operating experiences.

EMERGENCY OPERATING PROCEDURES

This paragraph contains recommended actions in case of electrical power failure or loss of other treatment units and the effect on the unit process. Additional suggestions on provisions for maximizing plant reliability during emergencies resulting from failure of plant components may be found in "Design Criteria for Mechanical, Electric, and Fluid System and Component Reliability", EPA-430-99-001 (no date). Guidance on emergency planning may also be found in "Emergency Planning for Municipal Wastewater Treatment Facilities", EPA-430/9-74-013, February, 1974.

COMMON DESIGN SHORTCOMINGS

This information is based on actual full scale plant experiences. It is intended to outline common plant design shortcomings and easily implemented facility modifications to overcome the deficiency or compensate for the deficiency. This information may not apply to all plant situations and should be used only with competent engineering advice.

TROUBLESHOOTING GUIDE

This is a condensed action-reaction type presentation which covers a number of common unit process problems, symptoms, and corrections.

MAINTENANCE CONSIDERATIONS

A sound maintenance management system can be a major, positive factor in the successful long-term performance of a municipal wastewater system. The agency responsible for the wastewater system must give full support to the maintenance program if it is to be successful. The records from a good maintenance system are also very useful in preparing realistic budgets and in planning an adequate inventory of replacement parts. Where inadequate maintenance programs are a source of problems, the following references will be helpful.

Manufacturer's operation and maintenance manuals.

"Maintenance Management Systems for Municipal Wastewater Facilities", EPA 430/9-74-004, October, 1973.

"Considerations for Preparation of Operation and Maintenance Manuals", EPA 430/9-74-001 (no date).

"Operation of Wastewater Treatment Plants", Manual of Practice No. 11, Water Pollution Control Federation (1976) (Chapter 30).

This manual outlines general maintenance considerations, but a detailed program must be developed for each specific plant. Generally, the manufacturer's maintenance manual should be used as a basis for developing this program.

SAFETY CONSIDERATIONS

Although safety related problems may not contribute to process malfunctions, the operator should be alert for obviously hazardous conditions for both his protection and the protection of the operating staff. Typical safety considerations are outlined in this manual for each unit process. The following references will be useful.

"Safety in Wastewater Works", Manual of Practice No. 1, Water Pollution Control Federation (1969).

"Operation of Wastewater Treatment Plants", Manual of Practice No. 11, Chapter 31, Water Pollution Control Federation (1976).

REFERENCE MATERIAL

Pertinent reference materials, formulas, and definitions are provided as applicable to the specific unit process.

SECTION 3

GENERAL MAINTENANCE

There are a number of general maintenance considerations applicable to a number of unit processes. Those considerations are listed in this section and will not be repeated in each of the specific unit process sections.

Maintenance can be provided in-house or by outside contract services. Certain special services must be performed by outside services in many cases, but in-house maintenance for other requirements has generally been more satisfactory than use of contract services. It is recommended that in-house maintenance capability be developed for at least routine maintenance services.

1. A good preventative maintenance program is essential to continuity of service required for reliable plant operation. Preventative maintenance should include regular inspection, painting, lubrication, and minor and major overhaul on a scheduled basis. A good recordkeeping system is essential to a successful program.

2. Operating personnel should always be alert for unusual noises and other sensory indications of impending problems. Such indications should be checked out immediately upon detection to help prevent more serious equipment failures.

3. Lubrication is essential to proper equipment operation. Manufacturer's recommendations should be followed as related to intervals, methods, and types of lubricants. Overlubrication of ball and roller bearings should also be avoided. Oil leaks should be corrected promptly for safety reasons and because they indicate a developing maintenance problem.

4. Painting of plant components at reasonable time intervals will make cleaning an easier chore, and will help to prevent rust and deterioration of tankage and equipment. Use of proper surface preparation and application of proper coatings will provide long term advantages even though the initial cost and time required may be greater. If surfaces are recoated at proper intervals it may be that only the top coat will have to be applied rather than complete replacement of base coats. Paint manufacturers provide excellent guidelines on the use of their products for various services.

5. Concrete surfaces and expansion joints should be inspected for deterioration on an annual basis. Patchwork, recalking, and sealing should be done promptly when the need for such repair becomes apparent.

6. Drive systems should be inspected regularly for worn belts, chains, pulleys, sprockets, and flexible couplings. Proper lubrication should be provided. Drive systems should be adjusted at intervals to provide proper chain or belt tension.

7. Proper housekeeping is important to morale, safety, and maintenance. Areas should be kept clean and spills should be cleaned up promptly. Conditions that cause continuing clean-up problems should be corrected so that the problems are eliminated or minimized. Walkways should be kept clear of water, oil, grease, leaves, snow, ice, and other similar conditions.

8. Valves and gates should be operated at regular intervals (typically every month) to assure free operation and to check on adequacy of lubrication.

9. Sludge lines should receive particular attention. These lines should be inspected periodically for buildups and should be flushed and cleaned as necessary to remove sludge and grit accumulations. The required intervals must be determined based on plant experience.

10. All maintenance work should consider the potential presence of sewage gases. Maintenance personnel should be familiar with the types of gases, potential locations where the gases can be expected, monitoring procedures, proper ventilation procedures, and proper work procedures.

11. Tankage should be drained at least once a year so submerged equipment can be inspected and repaired. At the same time protective coatings can be repaired.

SECTION 4

GENERAL PROCESS STARTUP PROCEDURES

This section contains general process startup considerations which are applicable to most unit processes. These considerations will not be repeated in each manual. Careful and systematic process startup procedures will help to prevent damage to equipment and minimize safety hazards to operating personnel.

1. Clean all debris from tankage, pipelines, and from the vicinity of equipment. Assure that all packing material and shipping tiedowns are removed per manufacturer's instructions.

2. Check all protective coatings for damage and repair as necessary.

3. Provide initial lubrication. Be sure all oil reservoirs are properly filled. Remove any temporary protective coatings which were applied for shipping protection.

4. Operate all valves, shafts, and other mechanical components prior to filling with process liquid where possible. Adjust drives, belt tension, alignment, and other items at this time.

5. Adjust weirs and troughs to approximate position.

6. Check electrical components for operational status. Check out control circuits as possible on a "dry-run" basis prior to operation of drive.

7. Check all motors for correct voltage connections at the terminal box.

8. Check all motors for proper direction of rotation.

9. Pressurize piping with water to check for leaks, where possible.

10. Check out and calibrate instrumentation, controls, and safety devices.

11. Check that the necessary chemicals are on hand for initial operation.

12. When tankage is filled, the weirs can be adjusted to final level.

13. Start up all support facilities such as service water, air supply, hot water, and similar facilities.

14. Make sure safety equipment is available.

SECTION 5

OPERATION AND MAINTENANCE MANUALS

I

CHEMICAL CONDITIONING

CONTENTS

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PROCESS DESCRIPTION

The most frequently encountered conditioning practice is the use of ferric chloride either alone or in combination with lime, although the use of polymers is rapidly gaining widespread acceptance. Although ferric chloride and lime are normally used in combination, it is not unusual for them to be applied individually. Lime alone is a fairly popular conditioner for raw primary sludge and ferric chloride alone has been used for conditioning activated sludges. Lime treatment to a pH of 10.4 or above has the added advantage of providing a significant degree (over 99 percent) of disinfection of the sludge according to "Water Supply and Treatment", Bulletin 211, published by the National Lime Association.

chemicals

Organic polymer coagulants, and coagulant aids have been developed in the past 20 years and are rapidly gaining acceptance for sludge conditioning. These polymers are of three basic types:

polymers

1. Anionic (negative charge) - serve as coagulants aids to inorganic Al^{+++} and Fe^{+++} coagulants by increasing the rate of flocculation, size, and toughness of particles.
2. Cationic (positive charge) - serve as primary coagulants alone or in combination with inorganic coagulants such as aluminum sulfate.
3. Nonionic (equal amounts of positively and negatively charged groups in monomers) - serve as coagulant aids in a manner similar to that of both anionic and cationic polymers.

The popularity of polymers is primarily due to their ease in handling, small storage space requirements, and their effectiveness. All of the inorganic coagulants are difficult to handle and their corrosive nature can cause maintenance problems in the storing, handling, and feeding systems in addition to the safety hazards inherent in their handling. Many plants in the U.S. have abandoned the use of inorganic coagulants in favor of polymers.

equipment

The facilities for chemical conditioning are relatively simple and consist of equipment to store the chemical(s), feed the chemical(s) at controlled dosages, place the chemical(s) in solution or slurry, and feed the solution to the process as shown in Figure I-1.

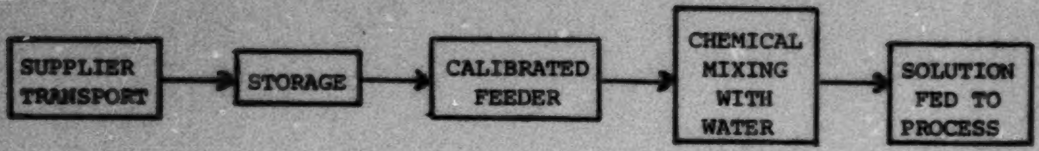


Figure I-1. Chemical conditioning system schematic.

The equipment used for storing and handling these chemicals varies with the type of chemical used, liquid or dry form of the chemical, quantity of chemical used, and plant size. Storage requirements vary, but typically may be 15 to 30 days of use or 150 percent of the bulk transport capacity, whichever is greater.

ferric chloride storage

Dry ferric chloride is obtained in 18 and 40 gallon steel drums. Storage requirements consist of a dry storeroom. Once the drums are opened the contents should be used or mixed with water and stored in solution. Liquid ferric chloride is shipped in tank trucks or by rail tanker. Storage tanks must be lined with corrosion resistant material such as rubber, lead, stainless steel, Duriron or plastic. Fiberglass reinforced plastic (FRP) storage tanks have become more popular in recent years. The handling equipment construction materials, especially mixing tanks must also be heat resistant due to the amount of heat given off when ferric chloride is mixed with water. In areas of cold weather the storage and feed equipment should be heated or the solution diluted to prevent crystallization.

Lime is purchased in the dry form. There are several compounds available, but pebble quicklime (CaO) and hydrated lime $Ca(OH)_2$ are the most commonly used for sludge conditioning. Hydrated lime is usually used for small facilities and quicklime for large facilities.

lime storage

Storage and handling facilities are the same for either compound. Small plants using bagged lime require a waterproof storage building. Large plants using bulk lime require water tight and air tight storage units. Unlike ferric chloride, lime is not corrosive to steel, so conventional steel or concrete bins or silos can be used as shown in Figure I-2 (see following page).

lime handling

Handling may be accomplished manually for bagged lime or with bucket elevators and/or screw conveyors for bulk systems. Pneumatic trucks and rail cars have recently been developed which blow the lime into the storage units, thus eliminating the need for mechanical conveyors for unloading.

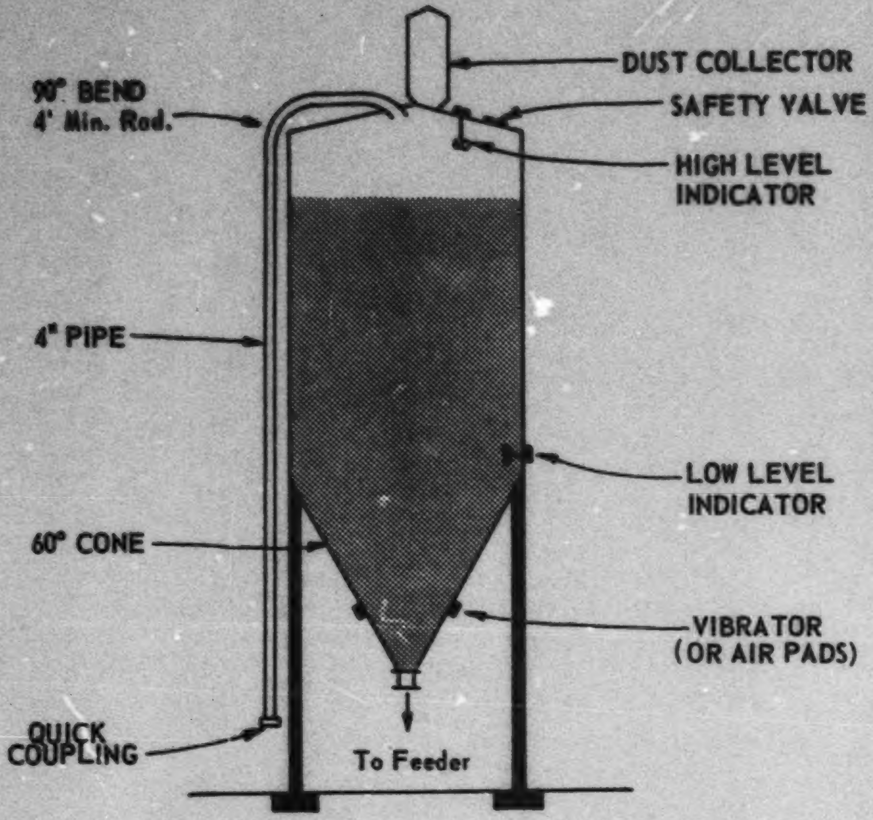

DUST COLLECTOR
90° BEND
4' Min. Rad.
SAFETY VALVE
HIGH LEVEL INDICATOR
4" PIPE
LOW LEVEL INDICATOR
60° CONE
VIBRATOR (OR AIR PADS)
QUICK COUPLING
To Feeder

Figure I-2. Typical bulk storage tank.

Polymers for sludge conditioning are available in liquid, powder, or pellet form. The polymers are purchased in concentrated form and mixed or diluted with water before use. It has been found that polymer concentrations as low as 0.01 percent perform efficiently in sludge conditioning. Presumably, at such dilute concentrations the polymer molecules can perform at maximum efficiency.

polymer forms

Although the liquid form is the easiest to mix with water, it is also expensive because of high transportation costs. The most expensive form is pellets, that are also easy to mix. Powders can be difficult to mix, but they are the least expensive. Powdered polymers can cause housekeeping problems by making floors extremely slippery and being difficult to clean up.

polymer storage

Powdered polymer is available in 25 pound multi-wall paper bags. Storage areas should be dry. Liquid polymer is available in 5 gallon pails, 55 gallon steel drums, and tank trucks. Liquid polymer should be stored in heated buildings or tanks. Freezing does not harm the product, but low temperatures create handling difficulties due to greatly increased viscosity. Concentrated bulk storage should be in lined tanks. Generally, bulk storage is not feasible except for plants over 100 mgd because of the small feed dosages.

feeders

The feed systems consist of transfer from storage, mixing a given solution strength, and metering the solution to process or metering the chemical from storage to a slurry or solution and immediate transfer of the liquid to the process. There are many equipment variations available. The chemicals can be metered dry using dry feeders, in liquid form by metering pumps, or known concentration solutions can be prepared and then metered with metering pumps.

In large plants dry chemicals are transferred to hoppers by screw conveyors. Dry feeders then add the chemical to mixing or slurry tanks. Bulk quicklime is normally fed to a slaking device where the oxides are converted to hydroxides, producing a paste or slurry, which is then further diluted before being piped or pumped to the process.

There are two types of dry feeders - volumetric and gravimetric. As the names imply, the volumetric feeder meters a repeatable volume of chemical and the gravimetric feeder meters a repeatable weight of material.

There are six commonly used types of volumetric feeders. They are roll feeder, screw conveyor, belt feeder, rotary paddle feeder, oscillatory hopper feeder, and vibratory feeder.

Gravimetric feeders can be classified into three groups: pivoted belt, rigid belt and loss-in-weight hopper. These feeders automatically compensate for difference in form, size, or density to feed a repeatable weight of chemical. The feed rate is adjusted by actively weighing the material being fed.

TYPICAL DESIGN CRITERIA & PERFORMANCE

Feed rates for chemical conditioning of sludges are extremely variable depending on process used, nature of the sludge, and type of chemical. Typical range of dosages are as follows:

	$FeCl_3$, lb/dry ton solids	Lime, lb CaO/dry ton solids	Polymer, lb/dry solids
Raw primary + waste activated sludge	40-50	110-300	15-20
Digested primary + waste activated sludge	80-100	160-370	30-40
Elutriated primary + waste activated sludge*	40-125	-	20-30

*Elutriated sludge results from a process whereby the sludge is washed with either fresh water or plant effluent to reduce the demand for conditioning chemicals and to improve settling of filtering characteristics.

STAFFING REQUIREMENTS

Labor requirements include unloading, storing, and feeding chemicals and are shown in Table I-1. Labor requirements were developed from "Costs of Chemical Clarification of Wastewater", EPA Contract No. 68-03-2186, final draft, December, 1977.

TABLE I-1. CHEMICAL CONDITIONING LABOR REQUIREMENTS

Chemical	Capacity, lb/hr	Operation & maintenance labor, hr/yr
Ferric chloride	10	150
	50	210
	100	300
	500	800
Lime (slaked)	100	1,800
	500	1,850
	1,000	2,100
Lime (unslaked)	100	2,400
	500	2,400
	1,000	2,900
Polymer (dry)	.5	500
	1.0	580
	5.0	750
	10.0	850
Polymer (liquid)	.5	390
	1.0	400
	5.0	420
	10.0	440

NORMAL OPERATING PROCEDURES

Caution:

Check all equipment and work areas for spilled chemicals. Chemicals, especially polymers, that have been spilled on the floor can cause slippery areas if moisture is also present. Some chemicals such as sodium hydroxide are a safety hazard if spilled.

Startup

Lime Feeding System (including slaker)

1. Turn on the main water supply valve, thus allowing water to fill the slaking chamber.

2. Start up the vapor and dust collection system.

3. When slaking chamber is approximately 1/4 full of water close by-pass valve.

4. Turn on the water supply to the slaker spray nozzles. These should be directed along the center of the separator weirs. Spray should be centered along the edge of the weir.

5. Start the slaker grit conveyor.

6. Adjust the water valve to pass the recommended water rate. Optimum water quantity varies with the grade of lime and the size of the grit particles that are to be removed but typical ratios are 3 to 5 pounds of water per pound of quicklime. Adjust flow by characteristics of grit being removed. If lime is being washed out with the grit, flow is too high and should be reduced. Slurry temperature in the slaker should be 150°F to 170°F.

7. Turn on the paddle shaft drive.

8. Start chute vibrator or tapper.

9. Set feeder to desired feed rate and start.

10. Open the chute valve to admit lime to the feeder. The feeder should start feeding lime to the slaking chamber where it should be slaked into paste form, discharged over the separation weirs, diluted to a slurry in the separator chamber, and delivered through the slaker discharge.

11. After operation has stabilized, adjust the water valve to obtain the desired slaker performance.

12. After slaker has been in operation for 15 or 20 minutes, examine the grit being discharged from the grit remover. If necessary, re-adjust the water flow to obtain optimum grit removal. Decreasing the flow will result in the removal of finer grit particles and will increase the total amount of grit removed. Increasing the flow will result in the removal of coarser grit and will decrease the total amount of grit particles. It is possible to remove an insert located where the slaker connects to the grit conveyor. For a given flow, removal of the insert will result in the removal of more fine particles and increase the total amount of grit removed.

Dry Polymer Feed System

1. Weigh the amount of dry polymer to be mixed.

2. Determine amount of mixing water to be used to produce the desired mixture concentration.

3. Turn on mixing water supply valve.

4. Pour measured amount of polymer through eductor funnel while mixing water is flowing.

5. Turn on mixer when water level is up to the propeller.

6. Shut off mixing water when correct volume of mixing water has been added.

7. Allow mixer to run 30 to 60 minutes, then shut off.

8. Transfer solution to feed tank if two tank system is used.

9. Set feed pump using charts to determine setting for desired dosage.

10. Check to see that feed line valves are open.

11. Start pump.

Liquid Chemical Feed Systems (all chemicals)

1. Dilute liquid chemical as needed if dilution system is provided.

2. Transfer dilute solution to feed tank.
3. Set feed pump using charts to determine setting for desired dosage.
4. Check to see that feed line valves are open.
5. Start flow of dilution water (on discharge of pump) if used.
6. Start feed pump.

Routine Operations

1. Inspect the system twice a shift and make necessary dosage changes.
2. Make sure feeders are continuing to pump by observing draw down in solution tanks occasionally.
3. If feeders are not automatically proportioned to flow rate, the feed rate must be changed each time the flow rate is changed.

Shutdown

Lime Feed System

1. Stop the feeder.
2. Close the valve in the chute which supplies lime to the feeder.
3. Stop the slaker paddle shaft drive.
4. Stop the slaker grit conveyor drive.
5. Turn off water supply to slaker spray nozzles.
6. Shutdown the vapor and dust collection system.
7. Turn off water supply to slaker.

Other Chemical Feed Systems

The other systems are shutdown by turning off the feeder and dilution water if used.

CONTROL CONSIDERATIONS

Physcial Control

If the feeders are automatically paced to flow, feed rate adjustments are required only to compensate for varying dosage requirements. If the feeder is not paced to flow the feed rate must be adjusted each time the plant flow rate is changed. The lime slaker requires occasional adjustment for variations in lime quality.

EMERGENCY OPERATING PROCEDURES

Loss of Power

The chemical feed system will normally shutdown during power outages becasue the drives are electrical. It may be desirable to close the water supply valves after the feed lines are flushed unless the water supply also shuts down during the outage.

COMMON DESIGN SHORTCOMINGS

Shortcoming	Solution
1. Dry feed chemicals deposit in feeder.	1. Provide mechanical mixers for dissolving solids and maintaining them in suspension prior to delivery to feeder.
2. Liquid chemicals crystalize or become too viscous in storage.	2a. Improve insulation.
	2b. Order lower concentration from supplier.
	2c. Dilute slightly when chemical is delivered to the storage tank.
	2d. Heat the storage area.
3. Feed system capacity inadequate.	3a. Add equipment.
	3b. Increase chemical solution strength (CAUTION: polymer concentrations greater than 0.5 to 1 percent may be difficult to prepare or too viscous to feed.)

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Cake or filtrate solids decreases.	1a. Improper chemical dosage (assuming no mechanical problem in dewatering device)	1a. Test for proper dosage (Buchner Funnel test, filter leaf test, or jar test).	1a. Correct dosage according to test results.
	1b. Mechanical failure in feed system.	1b. Visual inspection.	1b. Repair failure.
2. Air slaking occurring during storage of quicklime.	2a. Adsorption of moisture from atmosphere when humidity is high.	2a. Humidity, storage facility not airtight.	2a. Make storage facilities airtight, and do not convey pneumatically.
3. Feed pump suction or discharge line clogged.	3a. Chemical deposits.	3a. Visual inspection. 3b. Inspect check valves.	3a. Provide sufficient dilution water.
4. Grit conveyor or slaker inoperable.	4a. Foreign material in the conveyor.	4a. Broken shear pin.	4a. Replace shear pin and remove foreign material from grit conveyor.
5. Paddle drive on slaker is overloaded.	5a. Lime paste too thick.	5a. Visual inspection.	5a. Adjust compression on the spring between gear reducer and water control valve to alter the consistency of the paste.
	5b. Grit or foreign matter interfering with paddle action.	5b. Visual inspection.	5b. Remove grit or foreign materials or use a better grade of lime.
6. Lime deposits in lime slurry feed lines.	6a. Velocity too low.	6a. Check velocity in pipelines.	6a. Maintain high slurry velocity by use of a return line to the slurry holding tank. Better yet, the slurry should be transported in troughs with removable covers.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	6b. Inadequate mixing.	6b. Inspect mixing in slurry tank.	6b. Provide adequate mixing in slurry storage tank.
7. Incomplete slaking of quicklime.	7a. Too much water is being added.	7a. Hydrate particles coarse due to rapid formation of a coating.	7a. Reduce quantity of water added to quicklime (ratio to weight of water to lime should be 3:1 to 5:1 depending on lime and slaker).
8. "Burning" during quicklime slaking.	8a. Insufficient water being added, resulting in excessive reaction temperatures.	8a. Some particles left unhydrated after slaking.	8a. Add sufficient water for slaking (See Solution 7).
9. Chemical feed line ruptures.	9. Positive displacement pump has been started against a closed valve or plugged line.	9. Valves and line.	9. Open valves in feed line before pump is started. Be sure that line is open. A good procedure is to start flow of dilution water first.
10. Chemical concentration changes without varying setting.	10. New load of chemical with different moisture content, density, or chemical content.	10. Analyze moisture content, density, chemical concentration.	10. Recalibrate and adjust feeder accordingly.

SAFETY CONSIDERATIONS

Safety

dust

Dust from dry chemicals can be irritating to the respiration system if inhaled. In plant areas where chemical dust may be present such as bag handling areas, unloading areas, or around open feeders, workers should wear a lightweight filter mask and tight fitting safety glasses with side shields.

ferric chloride

Great care should be taken to AVOID THE CONTACT OF ANHYDROUS FERRIC CHLORIDE WITH ANY PART OF THE BODY, and especially with the eyes. The moisture present in the eyes or on the skin can cause sufficient heat to burn the skin. Ferric chloride solutions should be handled with the same care as acid solutions, since they can cause burns similar to those caused by acids. They are also injurious to clothing and cause difficult-to-remove stains. Personnel handling anhydrous ferric chloride or ferric chloride solutions should wear overalls, rubber apron, rubber gloves and chemical goggles. Floors, walls and equipment which are subject to splashing should be protected with corrosion-resistant paint or rubber mats.

first aid

If anhydrous ferric chloride comes in contact with the skin or clothing, DO NOT WASH IMMEDIATELY WITH WATER. Severe burns can result from the high heat produced when anhydrous ferric chloride is dissolved. Wipe off the excess ferric chloride first with a cloth, and then flood rapidly with large amounts of water.

If liquid ferric chloride comes in contact with the skin or clothing, wash it off immediately and thoroughly with water.

polymer

Dry polymer powder can be extremely irritating to eyes. Eye protection should be worn when handling powder. If powder gets in the eyes, flush with water. The major hazard with polymer handling is powder spilled on the floor which becomes wet thus causing extremely slippery surfaces. This powder remains slippery until washed down with large volumes of water.

lime

The problem of protection from quicklime burns is more serious, particularly in hot weather when workers are perspiring freely. Besides using eye protection and respirators workers exposed to quicklime dust should also wear proper clothing, including long-sleeved shirt with sleeves and collar buttoned, trousers with legs down over tops of shoes or boots, head protection, and gloves. Clothing should not bind too tightly around neck, wrists, or ankles. It is also advisable to apply a protective cream to exposed parts of body, particularly neck, face, and wrists.

Freshly slaked lime in stiff putty or milk form can produce burns when hot. After slurry is cool, contact with skin is virtually harmless, the principal effect being removal of natural skin oils. Therefore, workers who frequently handle lime slurry should oil their skin, where exposed, daily, using something similar to a petroleum jelly. This will help prevent chapping and thus reduce danger from burns or infection.

Workers inspecting or cleaning slakers should wear safety goggles.

After handling lime, operators should shower. If clothing has been subject to lime dust, or splattered with lime slurry, remove and launder. If possible, wear clean clothes every shift.

If lime gets in eyes, flush with large amounts of cold water immediately, followed by concentrated boric acid solution. Don't rub eyes if irritated by lime dust; doing this will only add to the discomfort. If the symptoms persist, a doctor should be consulted.

Lime burns should be treated similarly to caustic burns. Wash thoroughly with soap and warm water, then with vinegar to remove all lime. Apply burn ointment like boric acid salve and cover with sterile bandage. Keep bandaged during healing to prevent infection.

An efficient dust collecting and removal system is recommended at areas where lime is handled. An industrial vacuum can be used for cleaning up lime dust around and on equipment. The cleaner should be emptied after each use.

Quicklime bags should be stored in a clean, dry place to avoid moisture pickup. Otherwise the intense heat generated from accidental contact with water may be enough to start a fire in nearby flammable materials.

An important slaker safety measure is the installation of a thermostatic valve to prevent overheating and possible explosion. This could occur if the water supply fails and the lime feed continues, allowing the lime to overheat and produce excessive steam. The safety valve delivers a supply of cold water as soon as maximum safe slaker temperature is exceeded. An added safety feature is a high temperature alarm device.

Another important safety precaution is to avoid using the same conveyor or bin for alternately handling quicklime and one of the coagulants containing water of crystallization such as aluminum or ferric sulfate. The water of crystallization may be absorbed by the quicklime and could generate enough heat to cause a fire if the lime is in contact with bags or other combustibles. Explosions have also been reported to result from lime-alum mixtures in enclosed bins, where the intense reaction heat (1,100°F) liberated sufficient hydrogen from the water to create an explosive atmosphere. Therefore, if the facilities are to be used alternately, they should be cleaned thoroughly after every use. This hazard would not apply to hydrated lime.

REFERENCE MATERIAL

References

1. National Lime Association, Lime Handling Application and Storage, Washington, D.C. 20016.

2. BIF, "Engineering Data", West Warwick, R.I. 02893.

3. Penwalt Corporation, "Ferric Chloride", 3 Parkway, Philadelphia, PA. 19102.

Glossary of Terms and Sample Calculations

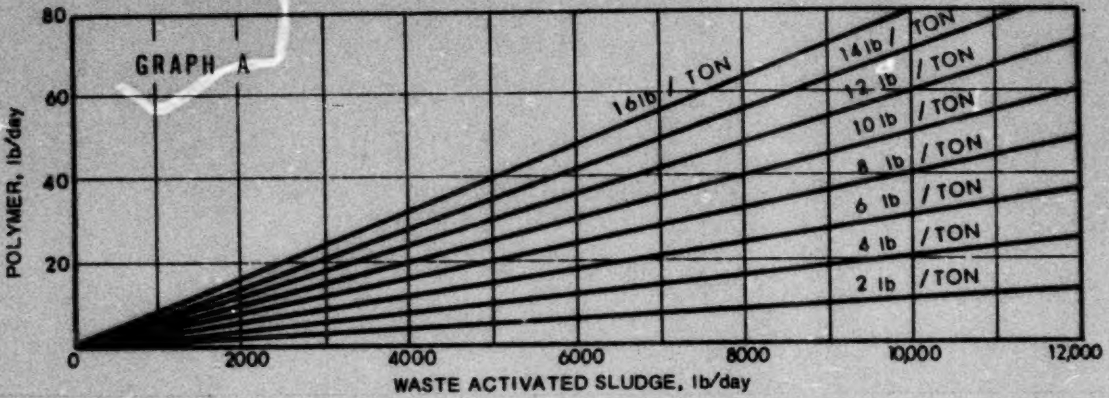
1. Elutriated sludge results from a process whereby the sludge is washed with either fresh water or plant effluent to reduce the demand for conditioning chemicals and to improve settling or filtering characteristics.

2. Anhydrous denotes materials without water; specifically, water of crystallization.

3. A hypothetical graphical method of determining proper polymer feed pump settings are shown in Figure I-3 (see following page). Graph A is used to determine total polymer requirements in pounds per day at various dosage rates. Graph B is then used to determine the required feed rate polymer solution.

   Finally, Graph C is used to determine correct polymer pump speed in rpm. Graphs A and B apply to the general case and Graph C applies to an assumed feed pump. A graph similar to Graph C can be prepared for the actual feed pump in a specific plant. For a specific pump the feed rate may be a function of rpm or stroke setting as applicable to the pump. As an example assume the following conditions:

   Sludge wasting rate = 7,000 lb dry solids per day



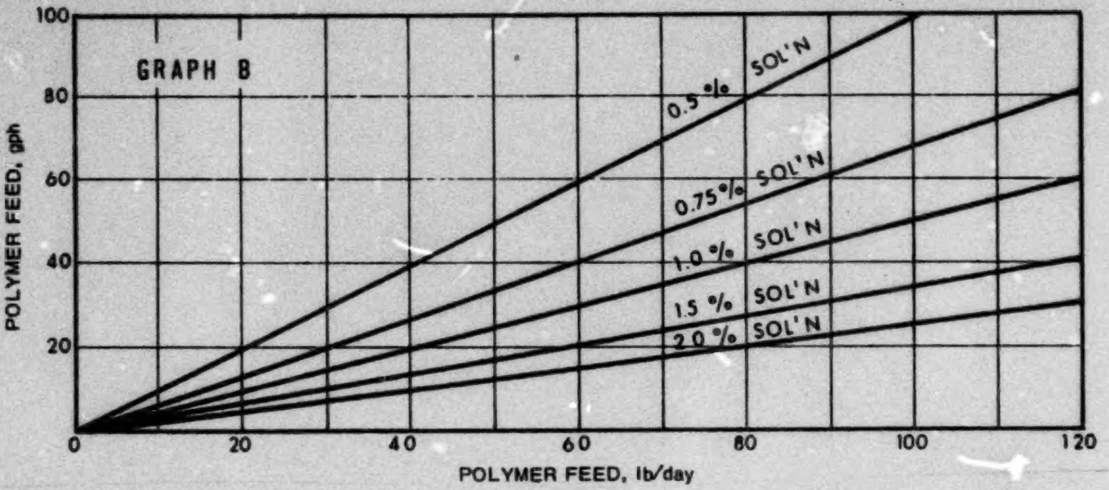


Figure I-3. Graphs A and B.

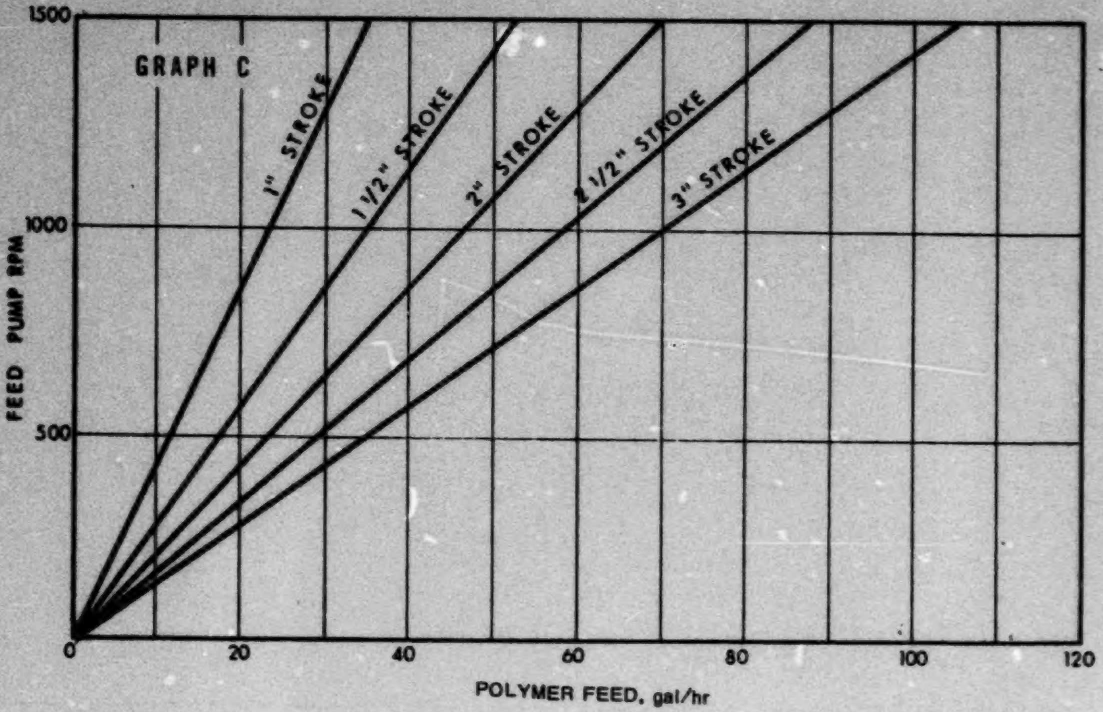


Figure I-3. Graph C.

Required polymer feed = 6 lb per ton dry solids (obtain from past experience, manufacturers recommendations, and lab tests).

Polymer solution mixture = 1 percent.

Pump stroke = 1 1/2 inches.

Using the 6 lb per ton curve on Graph A read required polymer on vertical axis = 21 lb per day.

Using the 1 percent curve on Graph B read required polymer feed rate on the vertical axis = 10 gph.

Using the 1 1/2 inch stroke curve on Graph C read required pump speed on the vertical axis = 300 rpm.

The following table is based on a polymer mix tank 4'-0" diameter x 4'-3" depth with a volume equivalent of 7.85 gallons per inch of depth. Approximately 6 inches freeboard should be reserved for mixing purposes to eliminate splashing. The following table illustrates a form to use in preparing a mixing guide for preparation of stock polymer solutions.

Vol. of solution to be prepared	Total available tank depth req'd (includes 6-inch freeboard	Pounds polymer to be added to tank to make up solution strength as noted				
		0.5%	0.75%	1.0%	1.5%	2.0%
50 gals	13 inches	2.1	3.15	4.2	6.3	8.4
100	19	4.2	6.30	8.4	12.6	16.8
150	25	6.3	9.45	12.6	18.9	25.2
200	32	8.4	12.60	16.8	25.2	33.6
250	38	10.5	15.75	21.0	31.5	42.0
300	44	12.6	18.90	25.2	37.8	50.4
350	51	14.7	22.05	29.4	44.1	58.8

II

GRAVITY THICKENING

CONTENTS

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PROCESS DESCRIPTION

Gravity thickening is the most common sludge concentration process in use at wastewater treatment plants in the United States. It is simple and inexpensive, but it may not produce as highly concentrated sludges as other thickening processes. Gravity thickening is a sedimentation process which is similar to that which takes place in all settling tanks; in fact, gravity thickening units physically and operationally look like sedimentation tanks. The objective of sludge thickening is to produce as thick a sludge as possible at minimum cost. Chemicals may be used to aid the process as described under CONTROL CONSIDERATIONS.

operation

Solids settle by gravity to the bottom of the basin forming a sludge blanket with a clearer liquid (supernatant) above. The supernatant is removed from the basin over weirs located near the top of the tank usually around the outer circumference. Thickening takes place as the sludge particles move to the bottom of the tank and the water moves toward the top. As the drive unit turns the mechanism the blanket is gently stirred, which helps compact the sludge solids and release water from the mass. Sludge solids are scraped toward a center well and withdrawn, normally by pumping.

design differences

Differences between various designs of gravity thickening units are mainly physical construction differences such as the way the sludge raking arms are supported and driven, arrangement of the arms, and whether skimming is provided. These physical differences do not have an effect on operation and maintenance except for the operator to note the maintenance requirements of the equipment at his plant as shown in the manufacturer's instructions.

A typical gravity thickener is illustrated in Figure II-1 (see following page).

supernatant return to process

Thickener supernatant is usually returned to either the primary or the secondary treatment process and normally causes no problem to process operation. The respective treatment process must be sized to treat the supernatant flow and organic loading in addition to normal plant flow.

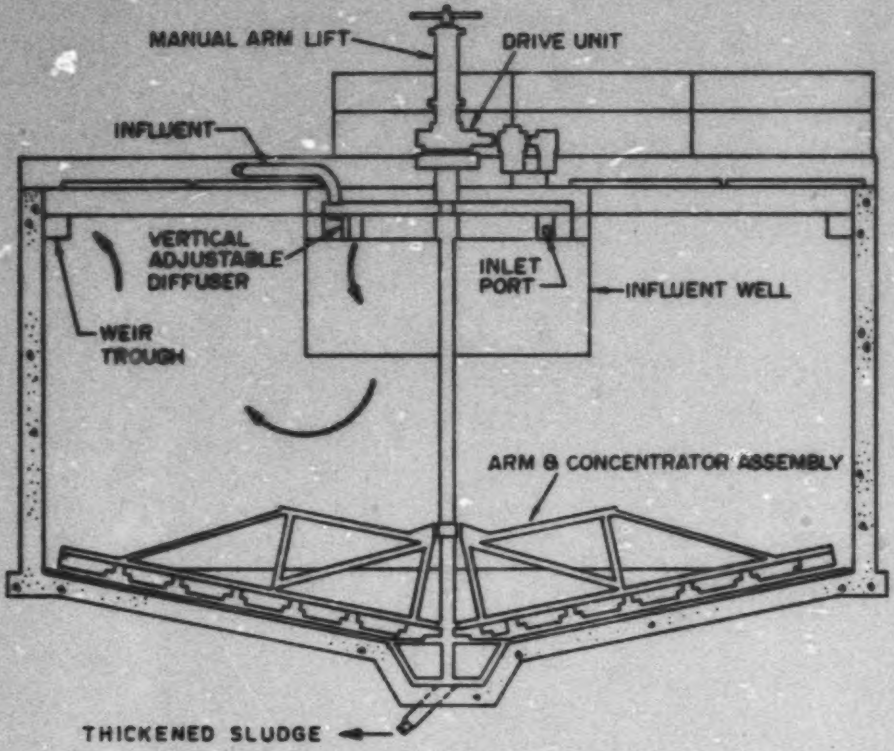

MANUAL ARM LIFT
DRIVE UNIT
INFLUENT
VERTICAL
ADJUSTABLE
DIFFUSER
INLET
PORT
INFLUENT WELL
WEIR
TROUGH
ARM & CONCENTRATOR ASSEMBLY
THICKENED SLUDGE

Figure II-1. Typical gravity thickener.

TYPICAL DESIGN CRITERIA & PERFORMANCE

Gravity thickeners are designed based on overflow rate (hydraulic loading) and solids loadings. The principles that apply are the same as those used in designing sedimentation tanks. Typically, a proposed design is checked for both overflow rate and solids loading and the final selection is based on a thickener design that will meet both of the design considerations. Current practice in the United States calls for design overflow rates of 400 to 800 gpd per square foot. The design solids loadings will vary with the type of sludge and typical loadings are shown in Table II-1 along with expected thickener performance. This table was developed from information in "Process Design Manual for Sludge Treatment and Disposal", EPA 625/1-74-006, October, 1974. Gravity thickening should remove 90 percent of the solids in the feed to the thickener as an average.

TABLE II-1. GRAVITY THICKENER TYPICAL LOADINGS AND PERFORMANCE

Sludge type	Influent solids concentration, percent	Typical solids loading rate, lb/sq ft/day	Thickened sludge concentration, percent
Raw primary	5.0	20-30	8.0-10
Raw primary + $FeCl_3$	2.0	6	4.0
Raw primary + low lime	5.0	20	7.0
Raw primary + high lime	7.5	25	12.0
Raw primary + WAS*	2.0	6-10	4.0
Raw primary + (WAS + $FeCl_3$)	1.5	6	3.0
(Raw primary + $FeCl_3$) + WAS	1.8	6	3.6
Digested primary	8.0	25	12.0
Digested primary + WAS	4.0	15	8.0
Digested primary + (WAS + $FeCl_3$)	4.0	15	6.0
WAS	1.0	5-6	2-3
Trickling filter	1.0	8-10	7-9

*WAS Waste activated sludge

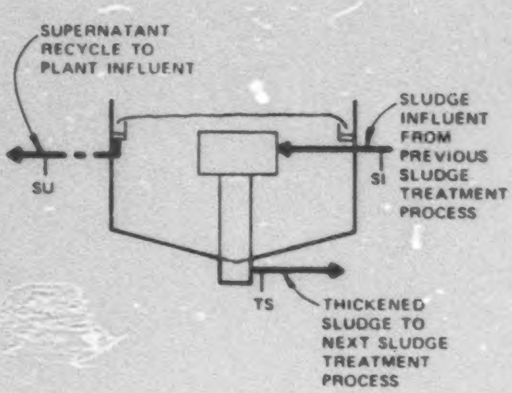
STAFFING REQUIREMENTS

Labor requirements for operation and maintenance of gravity thickeners are shown in Table II-2 (see following page). The requirements are based on the surface area of the thickener and include thickening and removal of sludge from the thickener, but do not include any allowances for chemical addition.

TABLE II-2. GRAVITY THICKENER LABOR REQUIREMENTS

Thickener surface acre, sq ft	Labor, hr/yr Operation	Maintenance	Total
Less than 500	310	180	490
1,000	350	200	550
2,000	420	240	660
5,000	680	370	1,050

MONITORING


SUPERNATANT RECYCLE TO PLANT INFLUENT
SU
SLUDGE INFLUENT FROM PREVIOUS SLUDGE TREATMENT PROCESS
SI
TS
THICKENED SLUDGE TO NEXT SLUDGE TREATMENT PROCESS

SUGGESTED MINIMUM	PLANT SIZE (MGD)	TEST FREQUENCY	LOCATION OF SAMPLE	METHOD OF SAMPLE	REASON FOR TEST
TOTAL SOLIDS	ALL	1/D	TS SI	G	P C
SUSPENDED SOLIDS	ALL	1/D	SU	G	P
BOD	ALL	2/W	SU	G	P(1)
FLOW	ALL	R	SU	R	P(1)

A. TEST FREQUENCY

R - RECORD CONTINUOUSLY
D - DAY
W - WEEK

B. LOCATION OF SAMPLE

SI - SLUDGE INFLUENT
TS - THICKENED SLUDGE
SU - SUPERNATANT

C. METHOD OF SAMPLE

G - GRAB SAMPLE
R - RECORD CONTINUOUSLY

D. REASON FOR TEST

P - PROCESS CONTROL
C - COST CONTROL

E. FOOTNOTES:

1. FOR CONTROL OF PROCESS RECEIVING THIS FLOW.

NORMAL OPERATING PROCEDURES

Startup

1. Open thickener influent valve or gate and begin filling thickener.
2. When rakes are covered start the thickener drive.
3. Start up chemical feed, where used.
4. Set up the thickened sludge pumping and controls and place into operation.
5. Check operation of skimmer mechanisms, adjust so that scum is drawn into skimmer, and turn on water sprays if needed. (If thickener is equipped with skimmer)

Routine Operations

1. Inspect system twice a shift.
2. Carry out maintenance as required including cleanup and washdown.
3. Take samples as outlined in MONITORING Section.

Shutdown

1. Shut down chemical feed systems.
2. Close thickener influent valve or gate.
3. Shut down the thickener drive, if desired.
4. Drain the thickener, if desired, or shut down the thickened sludge pumping. Sludge should be pumped from the thickener if it is to be shut down for more than a day or two.
5. Turn off water sprays if thickener is equipped with sprays.

CONTROL CONSIDERATIONS

Physical Control

Typically the flow through the thickener is continuous and should be set for as constant a rate as possible.

torque

The drive mechanism normally turns continuously and contains a torque monitor which will shut down the drive and sound an alarm if the drive mechanism is overloaded.

sludge pumping

A review of Table II-1 will show that for many sludges the thickened sludge is only 2 or 3 times the concentration of the influent sludge. In order to maintain the thickener solids balance, the thickened sludge flow rate for these cases must be 30 to 50 percent of the influent flow. In most cases it will be advantageous to draw off thickened sludge continuously at a flow rate approximately equal to:

$$\begin{matrix}\text{Thickened sludge}\\ \text{flow rate, gpm}\end{matrix} = \begin{pmatrix}\text{Influent}\\ \text{flow, gpm}\end{pmatrix} \left(\frac{\text{Influent solids, \%}}{\text{Thickened solids, \%}}\right)$$

It is important to maintain an adequate thickened sludge flow rate or sludge will accumulate very rapidly in the thickener.

Process Control

Efficient and consistent operation of sludge thickening process and equipment depends on frequent monitoring, both sensory and analytical.

inspection

The thickener should be inspected once a shift. The supernatant should be relatively clear and the process should be free of odors. The supernatant should be clear enough to see down into the thickener at least one to two feet. After gaining some operating experience it should be possible to roughly judge the operation of the thickener by visual appearance of the supernatant and surface of the thickener.

odors

Odors from the thickener indicate that sludge is not being withdrawn rapidly enough and is becoming septic in the thickener. When the sludge becomes septic, gas is formed and this gas mixes with the sludge to cause the sludge to float to the surface. Sludge should be withdrawn on a more frequent schedule to cure this problem. If the problem is not cured, the supernatant will contain high BOD and SS and may upset the rest of the treatment process when returned to the main plant.

sampling

Sampling should be performed as outlined under MONITORING. These samples may be obtained through valves provided in the respective thickener piping. If sampling points are not provided, they should be installed to facilitate operation and control of the process. Samples of the supernatant can be obtained at the overflow weir.

analysis

Samples should be analyzed according to procedures specified in STANDARD METHODS and, in addition, should be visually analyzed.

visual analysis

The influent sludge sample, when left undisturbed for about 30 minutes in a beaker, should separate into a well defined layer of sludge in the bottom and a relatively clear liquid (supernatant) above. If the separation does not take place in the beaker, problems can be expected in thickener operation. Either the plant treatment process is not operating properly or the sludge is not being properly pretreated prior to thickening (if chemicals are being added). Very little sludge should settle from the sample of supernatant in 30 minutes. If sludge does settle in the supernatant sample, it indicates that either the thickener is being overloaded (too dilute of an influent flow) or the sludge level is too high and is carrying over the weirs.

The following major variables affect the operation of gravity thickening and are discussed in this section.

1. Sludge blanket
2. Solids concentration
3. Liquid temperature and seasonal variations
4. Loading rates
5. Chemicals
6. Waste activated sludge

sludge blanket

Thickening experience indicates the need to maintain a sludge blanket in a thickener to assist in compaction. This compaction results from layers of solids exerting a squeezing or compressing force on those below. The sludge blanket level is generally controlled by the sludge withdrawal rate. Sludge should be removed from the thickener in small amounts several times daily rather than in large amounts less often to prevent the development of septic conditions within the thickener. The sludge level should be kept well below the top of the thickener. The level of the sludge can be checked using a portable sludge level detector or by probing for the top of the sludge blanket using a pole with a one foot square plate fastened perpendicularly to the bottom of the pole.

solids

In general, a thicker sludge will be obtained with a decrease in the sludge volatile solids content. The effect of the initial solids concentration varies, but in general it has been found that optimum results are achieved when the influent solids concentration is between 0.5 and 1.0 percent. Within this range, sludge compaction and supernatant clarity are optimized.

temperature

The liquid temperature has an effect on operation of the thickening process. Generally, during warm weather periods the blanket should be maintained at lower levels because of accelerated biological degradation and the possibility of septic conditions developing. Odor is a good indicator of this condition and the solution is to pump the thickened sludge at a higher rate. Conversely, deeper sludge blankets can be maintained when liquid temperatures are lower. The liquid temperature may also affect the thickener performance and, in some cases, the concentration of thickened sludge in summer may be as low as 60 percent of that obtained in winter operations.

loading rates

Overflow and solids loading rates are also important. The plant operating manual may call for specific loading rates, however, if performance is not satisfactory, the operation should be changed. For example, if it is found that sludge is not thick enough, the operator should try running at a lower overflow rate by decreasing the influent sludge flow. The operator should also try to identify any hydraulic disturbances within the thickener and these should be corrected by proper modifications such as baffling. If the sludge flow to the thickener is far below the design rate, pumping of secondary effluent to the thickener to bring hydraulic flows up closer to design overflow rates may help the operation and also minimize odor generation. Typical solids loading rates for various types of sludges are shown in II-1.

polymers

Polymers may be used to improve the performance of gravity thickeners. Because of the large number of polymers commercially available and the diversity of sludge types, it is necessary to do a number of jar tests to determine an optimum polymer and polymer dosage for a particular sludge. Typical polymer doses are one to five milligrams per liter (mg/l).

chlorine

Some plants have provisions for feeding chlorine to the thickener influent sludge. Chlorination of this sludge is effective in the oxidation of hydrogen sulfide and in the control of odor causing bacteria. A chlorine residual of 1 mg/l in the thickener supernatant should be adequate for odor control. Chlorine addition to thickeners increases the cost of operation and cannot be justified unless odor problems exist.

waste activated sludge

It is very difficult to gravity thicken waste activated sludge because of the light nature of the waste activated sludge solids. The addition of digested primary sludge to waste activated sludge has been found to help in the thickening of these solids. The amount of digested sludge to be applied to the thickener and the resulting performance will vary for each plant but, typically, should be in the range of 30 to 70 percent of the influent sludge flow. The optimum digested sludge flow can be determined by trying several ratios within the range of 30 to 70 percent.

EMERGENCY OPERATING PROCEDURES

Loss of Power

Short power interruptions should not greatly affect sludge thickening although electrical equipment will not operate, the thickening process will not deteriorate if power is regained within 30 minutes to an hour. If power is unavailable for longer periods, septic conditions may develop. The effect of potential septic conditions can be partially or totally overcome by aerating or mixing the contents of the thickener if practical and/or adding chlorine to the thickener contents.

Loss of Other Treatment Units

The loss of other treatment units should not greatly affect the operation of the thickener. The loss of the digesters or other processes to which thickened sludge is pumped may create a solids storage problem. It is not desirable to store sludge in the thickener, but in an emergency it can be used for sludge storage. In case of a prolonged problem it may be necessary to haul sludge to another treatment facility or disposal area.

COMMON DESIGN SHORTCOMINGS

Shortcoming	Solution
1. Scum carries over effluent weirs.	1. Install an adequate scum baffle just inside the effluent weir. This baffle should be slightly submerged and extend approximately 6 inches above the water surface.
2. Sludge contains excessive grit.	2. Install grit chamber at plant headworks (major construction), or eliminate sources of grit entering sewer system. (Make sure existing grit removal facilities are being properly operated.)

Shortcoming	Solution
3. Short circuiting flow through tank causing poor solids removal.	3. Modify hydraulic design and install appropriate baffles to disperse flow and reduce inlet velocities.
4. Corrosion of steel components.	4a. Coat surfaces with proper paint. Industrial paint suppliers and appliers can be located in the yellow pages of large city telephone directories. These suppliers can furnish complete recommendations on proper coating systems for various applications. See also WPCF MOP No. 17.
	4b. Install cathodic protection system in tank. Suppliers of this type of equipment will provide design assistance and can be found in the yellow pages under "Corrosion Control". Generally, cathodic protection should be installed only if the surface is protected by a coating which is at least 80 percent effective.

TROUBLESHOOTING GUIDE

GRAVITY THICKENING

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Septic odor, rising sludge.	1a. Thickened sludge pumping rate is too low.	1a. Check thickened sludge pumping system for proper operation.	1a. Increase pumping rate of thickened sludge.
	1b. Thickener overflow rate is too low.	1b. Check thickener collection mechanism for proper operation.	1b. Increase influent flow to thickener - a portion of the secondary effluent may be pumped to thickener if necessary to bring overflow rate to 400 to 600 gpd/sq ft.
		1c. Check overflow rate.	1c. Chlorinate influent sludge.
2. Thickened sludge not thick enough.	2a. Overflow rate is too high.	2a. Check overflow rate.	2a. Decrease influent sludge flow rate.
	2b. Thickened sludge pumping rate is too high.		2b. Decrease pumping rate of thickened sludge.
	2c. Short circuiting of flow through tank.	2c. Use dye or other tracer to check for circuiting.	2c. Check effluent weirs: repair or relevel. Check influent baffles: repair or relocate.
3. Torque overload of sludge collecting mechanism.	3a. Heavy accumulation of sludge.	3a. Probe along front of collector arms.	3a. Agitate sludge blanket in front of collector arms with water jets. Increase sludge removal rate.
	3b. Foreign object jammed in mechanism.		3b. If problem persists drain thickener and check mechanism for free operation.
	3c. Improper alignment of mechanism.		3c. Attempt to remove foreign object with grappling device.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
4. Surging flow.	4a. Poor influent pump programming.	4a. Pump cycling.	4a. Modify pump cycling. Reduce flow and increase time.
5. Excessive biological growths on surfaces and weirs (slimes, etc.)	5a. Inadequate cleaning program.		5a. Frequent and thorough cleaning of surfaces. Apply chlorination.
6. Oil leak.	6a. Oil seal failure.	6a. Oil seal.	6a. Replace seal.
7. Noisy or hot bearing or universal joint.	7a. Excessive wear.	7a. Alignment.	7a. Replace, lubricate, or align joint or bearing as required.
	7b. Improper alignment.	7b. Lubrication.	
	7c. Lack of lubrication.		
8. Pump overload.	8a. Improper adjustment of packing.	8a. Check packing.	8a. Adjust packing.
	8b. Clogged pump.	8b. Check for trash in pump.	8b. Clean pump.
9. Fine sludge particles in effluent.	9a. Waste activated sludge.	9a. Portion of WAS in thickener influent.	9a. Better conditioning of the WAS portion of the sludge.
			9b. Thicken WAS in a flotation thickener.

MAINTENANCE CONSIDERATIONS

A good preventive maintenance program will reduce breakdowns which could be not only costly, but also very unpleasant for operating personnel. Plant components including the following should be inspected semiannually for wear, corrosion, and proper adjustment:

1. Drives and gear reducers
2. Drive chains and sprockets
3. Shaft bearings and bores
4. Bearing brackets
5. Baffles and weirs
6. Electrical contacts in starters and relays
7. Suction lines and sumps
8. Skimming units

SAFETY CONSIDERATIONS

The gravity sludge thickening equipment presents no special hazards, however, general safety considerations should apply. At least two persons should be present when working in areas not protected by handrails. Walkways and work areas should be kept free of grease, oil, leaves and snow. Protective guards and covers must be in a place unless mechanical/electrical equipment is locked out of operation.

REFERENCE MATERIAL

References

1. Standard Methods for the Examination of Water and Wastewater.

   American Public Health Association
   1015 Eighteenth Street, N.W.
   Washington, D.C. 20036

2. WPCF Manual of Practice No. 17 (WPCF MOP No. 17), Paints and Protective Coatings for Wastewater Treatment Facilities.

3. WPCF Manual of Practice No. 11, Chapter 8, Operation of Wastewater Treatment Plants, Sludge Conditioning.

Glossary of Terms and Sample Calculations

1. Overflow rate is the flow rate over the effluent weir divided by the liquid surface area or the influent flow rate minus the average sludge draw-off flow rate divided

by the liquid surface area. This parameter is normally expressed as gallons per day per square foot of surface area. The following table shows thickener supernatant flow rates which result in 600 gpd/sq ft overflow rates for various size units and a sample calculation.

Thickener diameter, ft	Supernatant flow rate for 600 gpd/sq ft overflow rate
10	33
20	130
30	294
40	523
50	818
60	1,178

The following is a sample overflow rate calculation for a 30 foot diameter thickener operating at a flow of 300 gpm.

$$\text{Overflow rate} = \frac{(\text{flow, gpm})\ \frac{60\ \text{min}}{\text{hr}}\ \frac{24\ \text{hrs}}{\text{day}}}{\frac{\pi d^2}{4}}$$

$$= \frac{(300)(60)(24)\ 4}{(3.14)(30)^2}$$

$$= 611\ \text{gpd/sq ft}$$

2. Removal is the removal of the solids through the thickening process expressed as a percentage of influent solids. This is very difficult to calculate accurately over a period of time unless rather extensive sampling and testing is performed. The removal can be calculated at any moment based on grab sampling as follows:

$$\text{Removal} = \frac{(\text{average sludge flow})(\text{sludge solids})}{(\text{average influent flow})(\text{influent solids})} \times 100$$

$$= 100 \left[\frac{(\text{average supernatant flow})(\text{supern. solids})}{(\text{average influent flow})(\text{influent solids})}\right] \times 100$$

All corresponding parameters such as flows or solids must be expressed in the same units.

As an example assume the following data all taken at the same time.

Influent flow	= 100 gpm	Solids = 1.0%
Sludge flow	= 18.3 gpm	Solids = 5.0%
Supernatant flow	= 81.7 gpm	Solids = 0.1%

$$\text{Removal} = \frac{(18.3)(5)}{(100)\ (1)} \times 100$$

$$= 91.5\%$$

or

$$= 100 - \left[\frac{(100-18.3)(0.1)}{(100)\ \ (1)}\right] \times 100$$

$$= 91.8\%$$

3. Sludge concentration is the weight of solids per unit weight of sludge. It can be calculated in percent as follows:

$$\text{Concentration} = \frac{\text{weight of dry sludge solids}}{\text{weight of wet sludge}} \times 100$$

4. Solids loading is the feed solids applied per day divided by the liquid surface area of the thickener. It is generally expressed as weight (pounds) of dry solids per day per square foot.

5. Supernatant is the clarified liquid which forms above the sludge layer during the settling process. The supernatant is the effluent flow from the gravity thickening process.

6. Weir loading is the supernatant flow rate divided by the linear footage of effluent weir. It is normally expressed as gallons per day per foot of weir.

III

FLOTATION THICKENING

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PROCESS DESCRIPTION

process

Sludge thickening by flotation is a process especially effective for light sludges. This process causes the sludge to float and the sludge is then skimmed from the surface of the thickener. Flotation is especially effective on activated sludge, which is difficult to thicken by gravity because of its low specific gravity. Air is injected into the incoming sludge under pressure. The sludge then flows into an open tank, either rectangular or circular, where at atmospheric pressure, much of the air comes out of solution as minute air bubbles. These bubbles attach themselves to sludge particles and float these particles to the surface. A sludge layer forms on the top surface of the tank contents and this layer is removed by a skimming mechanism for further processing.

operation

A typical air flotation system is shown in Figure III-1 (see following page). A portion of the flotation thickener effluent, or similar plant process stream, is pumped to a retention tank at 60 to 70 psig. Air is fed into the recirculation pump discharge line or the retention tank at a controlled rate and mixed by the flow from the reaeration pump discharging into the retention tank through eductors. The flow through the recycle system is metered and controlled by a valve located immediately before the mixing of the recycle stream with the sludge feed. Effluent recycle ratios range from 30 to 150 percent of the thickener influent flow. The recycle flow and sludge feed are mixed in a chamber at the flotation unit inlet. Flotation aids such as polymers, if used, are normally fed into this mixing chamber. The sludge particles float to the surface. The clarified effluent is discharged under a baffle and over an adjustable weir which controls the depth of penetration of the surface sludge skimming mechanism. Bottom sludge collectors are used for removal of any settled sludge or grit that may accumulate.

thickening

Sludge thickening occurs in the floating sludge blanket, which is normally 8 inches to 24 inches thick. The buoyant sludge and air bubble mixture forces the surface of the blanket above the water level, allowing water to drain from the sludge particles. Detention time in the flotation zone is not critical, provided the particle rise rate is sufficient and that horizontal flow velocity in the unit does not produce scouring and rewetting of the sludge blanket.

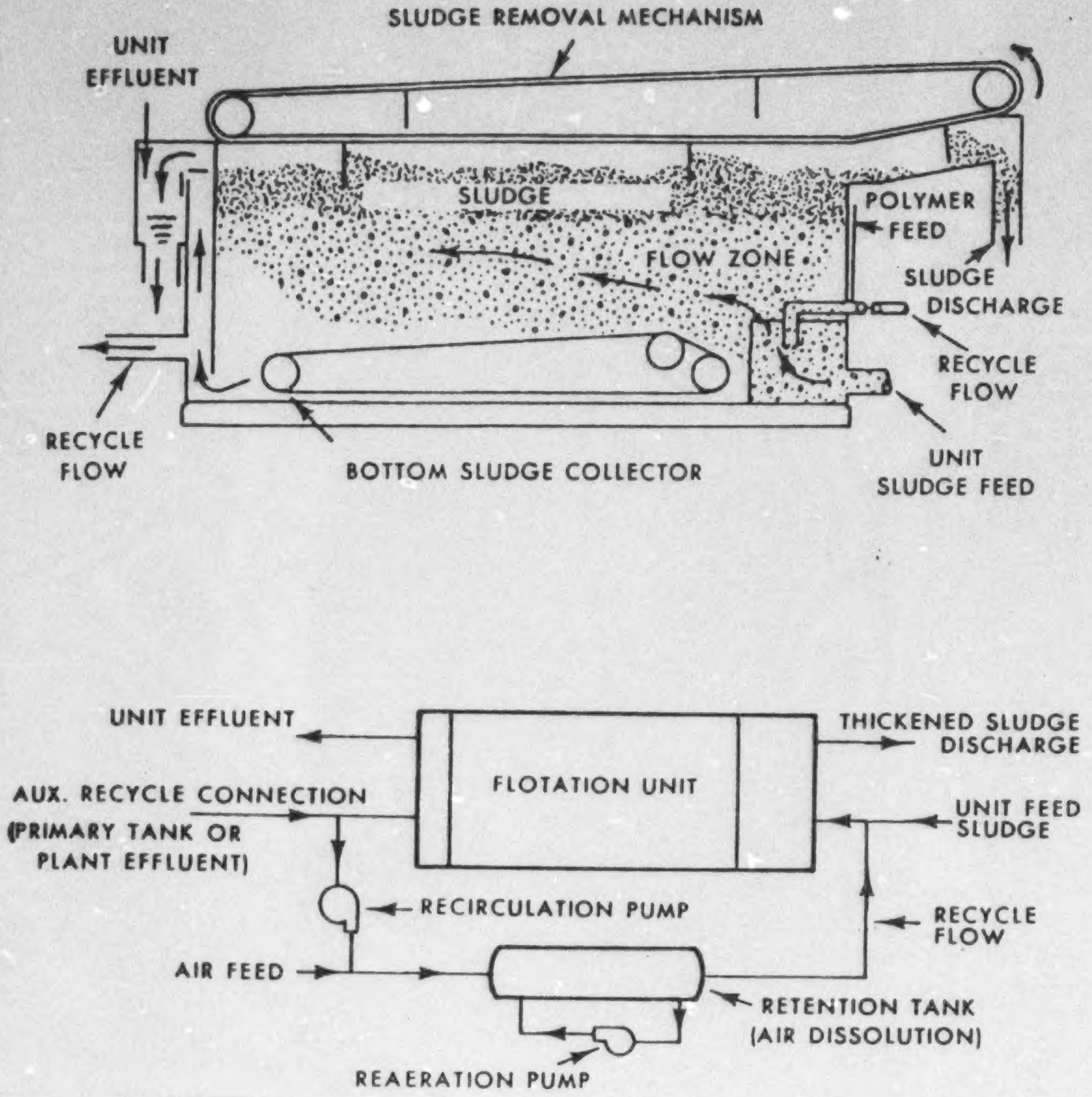

SLUDGE REMOVAL MECHANISM
UNIT EFFLUENT
SLUDGE
POLYMER FEED
FLOW ZONE
SLUDGE DISCHARGE
RECYCLE FLOW
UNIT SLUDGE FEED
RECYCLE FLOW
BOTTOM SLUDGE COLLECTOR
UNIT EFFLUENT
FLOTATION UNIT
THICKENED SLUDGE DISCHARGE
AUX. RECYCLE CONNECTION
(PRIMARY TANK OR PLANT EFFLUENT)
UNIT FEED SLUDGE
RECIRCULATION PUMP
RECYCLE FLOW
AIR FEED
RETENTION TANK (AIR DISSOLUTION)
REAERATION PUMP

Figure III-1. Dissolved air flotation system.

TYPICAL DESIGN CRITERIA AND PERFORMANCE

Flotation thickeners are typically designed based on solids loading, overflow rate, and influent solids concentration. Typical operation and performance parameters are shown in Table III-1 and were developed from manufacturer's operation manuals.

TABLE III-1. FLOTATION THICKENER OPERATION AND PERFORMANCE

Operation Parameter	Range	Typical
Solids loading, lb dry solids/hr/sq ft of surface		
With chemicals	2 to 5	2
Without chemicals	1 to 2	1
Influent solids concentration, mg/l	5,000 min	5,000 min
Air to solids ratio	0.02-0.04	0.03
Blanket thickness, in	8-24	-
Retention tank pressure, psi	60-70	-
Recycle ratio, % of influent flow	30-150	
Expected Performance		
Float solids concentration, %		3-7
Solids removal, %		
With flotation aid		95
Without flotation aid		50-80

Operating parameters for some actual plants are shown in Table III-2 (see following page), which was summarized in "Process Design Manual for Sludge Treatment and Disposal", (EPA 625/1-74/006).

STAFFING REQUIREMENTS

Labor requirements for operation and maintenance of flotation systems are shown in Table III-3 (see following page). The hours shown include thickening and removal of sludge to the next unit process.

TABLE III-2. DISSOLVED AIR FLOTATION - ACTUAL OPERATING CONDITIONS AND PERFORMANCE

Location	Feed	Influent ss mg/l	Subnatant ss mg/l	% Removal ss	Float % Solids	Loading lb/hr/ft^2	Flow gpm/ft^2	Remarks
Bernardsville, N.J.	M.L.[a]	3,600	200	94.5	3.8	2.16	1.2	Standard[c]
Bernardsville, N.J.	R.S.[b]	17,000	196	98.8	4.3	4.25	0.5	Standard
Abington, Pa.	R.S.	5,000	188	96.2	2.8	3.0	1.2	Flotation Aid[d]
					6.0			After 12 hours holding
Hatboro, Pa.	R.S.	7,300	300	96.0	4.0	2.95	0.8	Flotation Aid
Morristown, N.J.	R.S.	6,800	200	97.0	3.5	1.70	0.5	Standard
Omaha, Nebr.	R.S.	19,660	118	99.8	5.9	7.66	0.8	Flotation Aid
					8.8			After 24 hours holding
Omaha, Nebr.	M.L.	7,910	50	99.4	6.8	3.1	0.8	Flotation Aid
Belleville, Ill.	R.S.	18,372	233	98.7	5.7	3.83	0.4	Flotation Aid
Indianapolis, Ind.	R.S.	2,960	144	95.0	5.0	2.1	1.47	Flotation Aid
					7.8			After 12 hours holding
Warren, Mich.	R.S.	6,000	350	95.0	6-9	5.2	1.75	Flotation Aid
	M.L.							
Frankenmuth, Mich.	M.L.	9,000	80	99.1	6-8	6.5	1.3	Flotation Aid
Oakmont, Pa.	R.S.	6,250	80	98.7	8.0	3.0	1.0	Flotation Aid
Columbus, Ohio	R.S.	6,800	40	99.5	5.0	3.3	1.0	Flotation Aid
Levittown, Pa.	R.S.	5,700	31	99.4	5.5	2.9	1.0	Flotation Aid
Nassau Co., N.Y. Bay Park S.T.P.	R.S.	8,100	36	99.6	4.4	4.9	1.2	Flotation Aid
Nassau Co., N.Y. Bay Park S.T.P.	R.S.	7,600	460	94.0	3.3	1.3	0.33	Standard
Nashville, Tenn.	R.S.	15,400	44	99.6	12.4	5.1	0.66	Flotation Aid

[a] M.L. - Mixed liquor from aeration tanks.

[b] R.S. - Return sludge.

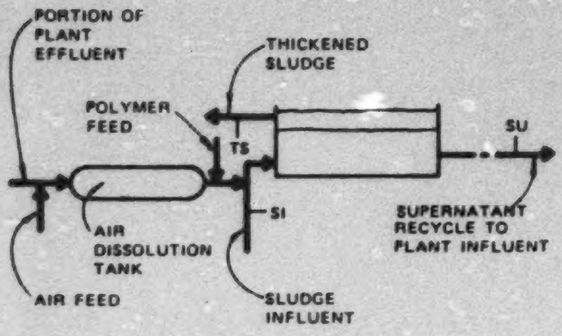
[c] Standard - Indicates no flotation aid and no holding before sampling.

[d] Flotation Aid - Indicates use of coagulant-flotation aid.

TABLE III-3. FLOTATION THICKENER LABOR REQUIREMENTS

Thickener surface area, sq ft	Labor, hr/yr Operation	Maintenance	Total
11	215	260	475
21	320	350	670
53	550	540	1,090
105	840	750	1,590
210	1,300	1,050	2,350
520	2,200	1,600	3,800

MONITORING


PORTION OF PLANT EFFLUENT
THICKENED SLUDGE
POLYMER FEED
TS
SU
SI
AIR DISSOLUTION TANK
SUPERNATANT RECYCLE TO PLANT INFLUENT
AIR FEED
SLUDGE INFLUENT

SUGGESTED MINIMUM

	PLANT SIZE (MGD)	TEST FREQUENCY	LOCATION OF SAMPLE	METHOD OF SAMPLE	REASON FOR TEST
TOTAL SOLIDS	ALL	1/D	TS SI	G	P C
BOD	ALL	2/W	SU	G	P(1)
SUSPENDED SOLIDS	ALL	1/D	SU	G	P
FLOW	ALL	R	SU	R	P(1)

A. TEST FREQUENCY

R - RECORD CONTINUOUSLY
D - DAY
W - WEEK

B. LOCATION OF SAMPLE

SI - SLUDGE INFLUENT
TS - THICKENED SLUDGE
SU - SUBNATANT

C. METHOD OF SAMPLE

G - GRAB SAMPLE
R - RECORD CONTINUOUSLY

D. REASON FOR TEST

P - PROCESS CONTROL
C - COST CONTROL

E. FOOTNOTES:

1. FOR CONTROL OF PROCESS RECEIVING THIS FLOW.

If polymer is used to aid in the flotation process, the optimal chemical dosage for the feed sludge should be determined at the start of each shift using jar test procedures. See the section on "Control Considerations" for more discussion.

NORMAL OPERATING PROCEDURES

Startup

1. Close drain valves as required.

2. Open appropriate valves on the recycle water system.

    a. If the unit has been drained, open the necessary valves to the auxiliary water supply.

    b. If the unit has not been drained do not open the auxiliary water supply valves.

3. Start the recirculation pump. If the unit has been drained wait until it is full and the auxiliary water supply valve has been closed before proceeding to Step 4.

4. Start the air feed and adjust to the required flow.

5. Start the chemical feed system.

6. Allow unit to run 10 to 15 minutes before starting influent sludge feed. This will charge the unit with chemical and aerated water.

Routine Operations

A check on the following unit operations at least twice per shift is recommended.

1. Visual check for proper chemical conditioning and mechanical operation. For example: large floc carrying over into recycle water indicates a problem with the reaeration system. A very turbid effluent with no floc development indicates a chemical deficiency or overloading of the unit.

2. Flow

3. Skimmer speed setting

4. Recycle rate

5. Chemical supply

6. Obtain and analyze samples as required

7. Chemical v-notch weir setting

8. Retention tank air cushion

A mechanical check should be made on the following units at two hour intervals.

1. Pumps: chemical feed, recycle, reaeration, and sludge sumps

2. Air manometer operation

3. Retention tank pressure

4. Sludge pit mixers

Shutdown

1. Shut off influent feed

2. Shut off chemical supply

3. If possible, allow unit to operate for 30 minutes before shutting down the sludge removal system (skimmer flights). This serves to clear the unit of suspensions and the sludge removal system clears the water surface of sludge. The unit can then be shut down with the flotation retention tank filled with practically clean water and the flotation unit primed for start-up.

4. Shut off air supply

5. Turn off reaeration pump

6. Turn off recirculation pump

7. Turn off sludge mechanism drive motor(s)

8. Shut off chain oilers

9. If no other units are operating to the same pit, shut off sludge pit mixer and pump.

10. If the unit is to be shut down for an extended period or for internal maintenance, it must be drained.

    a. Open drain valves on air flotation unit and retention tank.

10. b. Flush the unit, flights, beaching plate, baffles with the high pressure hose.

CONTROL CONSIDERATIONS

Physical Control

Typically the flow through the thickener is continuous and should be set for as constant a rate as possible.

torque

The drive mechanism normally turns continuously and contains a torque monitor or shear pins which will shut down the drive (and sound an alarm) if the drive mechanism is overloaded.

flow

Flow meters are normally provided for the flow through the thickener, the recycle flow, and the air flow.

retention tank

A control is normally provided on the retention tank to automatically control the liquid level by blowing off excess accumulations of air within the tank.

air compressor

The discharge pressure of the air compressor is normally regulated by a pressure reducing valve and is typically set at 75 psi.

Process Control

air

Air pressure in flotation is important because it determines air saturation or size of the air bubbles formed. It influences the degree of solids concentration and the subnatant (separated water) quality. In general, either increased pressure or air flow produces greater float (solids) concentrations and a lower effluent suspended solids concentration. There is an upper limit, however, as too much air will tend to break up floc particles.

air-to-solids

The air-to-solids ratio is important because it affects the sludge rise rate. The air-to-solids ratio needed for a particular application is a function primarily of the sludge's characteristics such as SVI. The most common ratio used for design of a waste activated sludge thickener is 0.03.

recycle

Additional recycle of clarified effluent does two things:

1. It allows a larger quantity of air to be dissolved because there is more liquid.

2. It dilutes the feed sludge.

Dilution reduces the effect of particle interference on the rate of separation. Concentration of sludge increases and the effluent suspended solids decrease as the sludge blanket detention period increases.

chemicals

Use of chemical flotation aids (polymers) provides improved thickening and solids capture. The quantities required must be determined for each specific sludge, but are usually in the range of 5 to 15 pound chemical per ton of dry solids.

The approximate chemical dosage and feed pump setting may be determined using the following procedure. Draw a 1,000 ml sample of representative influent sludge and with a pipette mix in chemical taken directly from the chemical mix tank. Note the ml of chemical required to produce a pronounced firm, well defined flox. Calculate the ratio of sludge volume to chemical volume, ml/ml. Using the daily sludge flow determine the daily chemical addition as follows:

chemical setting

$$\text{chemical flow, gpd} = (\text{sludge flow, gpd}) \left(\frac{\text{ml chemical}}{\text{ml sludge}}\right)$$

Check the chemical feed pump literature and set the adjustment so the pump feeds 1.5 to 2.0 times the calculated requirement of chemical solution. This feed rate can be reduced to optimum as the plant operates. Overfeed of chemical produces very little additional benefit, but increases operating costs.

sampling

Sampling should be performed as outlined under MONITORING. These samples may be obtained through valves provided in the respective thickener piping. If sampling points are not provided, they should be installed to facilitate operation and control of the process. Samples of the supernatant can be obtained at the overflow weir.

analysis

Samples should be analyzed according to procedures specified in Standard Methods and, in addition, should be visually analyzed.

visual test

Operating experience will allow most operators to judge the performance of the flotation thickener. A sludge rise test, performed as follows, is useful to visually check operating results. On most units, a sampling valve is provided on the inlet mixing chamber. When the unit is in operation, a quart jar sample is withdrawn and the time for the sludge to rise so that a clear separation between sludge and liquid can be seen. Normal rise times are 10 to 25 seconds, and experience will indicate an average time for each particular plant. The relative depth of the blanket, subnatant clarity and general appearance of flocculated sludge particles are also good visual indicators.

EMERGENCY OPERATING PROCEDURES

Loss of Power

The air flotation unit should be shut down unless emergency electrical generation is available. After power is restored a normal start up should be performed and the unit placed back in operation.

Loss of Other Treatment Units

Loss of chemical feed to the flotation unit will generally affect performance. If this occurs, operating parameters such as recycle ratio may require readjustment to obtain the best possible performance. Best performance without chemical feed will generally be very inferior to performance with chemical feed.

COMMON DESIGN SHORTCOMINGS

Shortcoming	Solution
1. Excessive wear in sludge mechanism chains and gears.	1. Install automatic oilers.
2. Poor results in mixing chemicals (polymers).	2a. Install automatic batching system or an aspirator wetting system to assure initial wetting of polymer (powders).
	2b. Prepare a less concentrated mixture of 0.25 to 0.5 percent by weight of polymer to water.
3. Early failure of pressure gauges and controls.	3. Install such equipment on panels isolated from equipment vibration.
4. Sludge feed pumps run on-off cycle causing pulsating feed to DAF unit.	4. Install a flow indicator and and flow control system to provide consistent, controllable inflow rate.
5. Only primary effluent available for auxiliary recycle.	5. Install line so that secondary effluent can be used for recycle during periods when primary effluent has more than 200 mg/l solids or contains unusual amounts of stringy materials.

Shortcoming	Solution
6. Wide variations in feed solids concentration occur due to direct feed of DAF from final clarifier.	6. Install a mixing-storage tank to minimize fluctuations.

TROUBLESHOOTING GUIDE

FLOTATION THICKENING

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Floated sludge too thin.	1a. Flight speed too high.		1a. Adjust flight speed as required.
	1b. Unit overloaded.	1b. Proper operation and calibration of polymer pumps.	1b. Turn off sludge feed and allow unit to clear or purge the unit with auxiliary recycle.
	1c. Polymer dosages too low.	1c. Proper operation and calibration of polymer pumps.	1c. Adjust as required.
	1d. Excessive air/solids ratio.	1d. Float appearance (very frothy).	1d. Reduce air flow to pressurization system.
	1e. Low dissolved air.		1e. See Item 2.
2. Low dissolved air.	2a. Reaeration pump off, clogged, or malfunctioning.	2a. Pump condition.	2a. Clean as required.
	2b. Eductor clogged.		2b. Clean eductor.
	2c. Air supply malfunction.	2c. Compressor, lines,	2c. Repair as required.
3. Effluent solids too high.	3a. Unit overloaded.	3a. See Item 1b.	
	3b. Polymer dosages too low.	3b. See Item 1c.	
	3c. Skimmer off or too slow.	3c. Skimmer operation.	3c. Adjust speed.
	3d. Low air/solids ratio.	3d. Poor float formation with solids settling.	3d. Increase air flow.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	3e. Improper recycle flow.	3e. Recycle pump flow rate.	3e. Adjust flow.
4. Skimmer blade leaking on beaching plate.	4a. Skimmer wiper not adjusted properly.		4a. Adjust
	4b. Hold-down tracks too high.		
5. Skimmer blade binding on beaching plate.	5. Skimmer wiper not adjusted properly.		5. Adjust
6. High water level in retention tank.	6a. Air supply pressure low.	6a. Compressor and air-lines.	6a. Repair
	6b. Level control system bleeding continuously.	6b. Level control system.	6b. Repair bleed system.
	6c. Insufficient air injection.	6c. Compressor and air lines.	6c. Increase air flow.
7. Low water level in retention tank.	7a. Recirculation pump not operating or clogged.	7a. Pump operation.	7a. Inspect and clean.
	7b. Level control system not bleeding air properly.	7b. Level control.	7b. Repair
8. Low recirculation pump capacity.	8. High retention tank pressure.	8. Recirculation flow rate.	8. Increase recirculation flow.

MAINTENANCE CONSIDERATIONS

A good preventive maintenance program will reduce breakdowns which could be not only costly, but also very unpleasant for operating personnel. The following are the major elements which should be inspected semiannually for wear, corrosion, and proper adjustment:

mechanical

1. Drives and gear reducers
2. Chains and sprockets
3. Guide rails
4. Shaft bearings and bores
5. Bearing brackets
6. Baffle boards
7. Flights and skimming units
8. Suction lines and sumps

SAFETY CONSIDERATIONS

The dissolved air flotation equipment presents no special hazards, however, general safety considerations should apply. At least two persons should be present when working in areas not protected by handrails. Walkways and work areas should be kept free of grease, oil, leaves and snow. Protective guards must be in place unless mechanical/electrical equipment is locked out of operation.

The retention tank is a hydropneumatic tank and should not be pressurized beyond the working pressure rating. The tank should have a functional relief valve and should be inspected on a regular basis for excessive corrosion.

REFERENCE MATERIALS

References

1. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, 1015 Eighteenth Street, N.W., Washington, D.C. 20036.

2. WPCF Manual of Practice No. 17 (WPCF MOP NO. 17), Paints and Protective Coatings for Wastewater Treatment Facilities.

3. WPCF Manual of Practice No. 11, Chapter 8, Operation of Wastewater Treatment Plants, Sludge Conditioning.

4. Process Design Manual for Sludge Treatment and Disposal, Chapter 4. EPA 625/1-74-006 U.S. EPA Technology Transfer.

5. Estimating Laboratory Needs for Municipal Wastewater Treatment Facilities. EPA 430/9-74-002 U.S. EPA Office of Water Program Operations, Washington, D.C. 20460.

Glossary of Terms and Sample Calculations

1. Overflow rate is the flow rate through the thickener divided by the liquid surface area normally expressed in gpd per sq ft.

2. Solids loading is the dry weight of sludge solids per unit time per square foot of thickener surface area. This is normally expressed as lb dry sludge solids per hr per sq ft of surface.

3. Air to solids ratio is the ratio of air feed to dry sludge solids feed by weight. The weight of air is 0.08 times the flow rate in standard cu ft per min.

$$\text{Ratio} = \frac{(0.08)\ (\text{Air flow, cfm})}{\text{Influent dm solids, lb}}$$

IV

AEROBIC DIGESTION

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PROCESS DESCRIPTION

process

Aerobic digestion is the separate aeration of waste primary sludge, waste biological sludge, or a combination of waste primary and biological sludges in an open or closed tank(s) in the presence of dissolved oxygen. The purpose is to further treat these sludges so that they will not cause odors or other nuisances in final disposal. Aerobic digestion also reduces the volume of sludge solids. Figure IV-1 (see following page) is a schematic diagram of an aerobic digestion system. Aerobic digestion is used commonly for package plants and many times is a part of the package plant tankage. Aerobic digestion is equally useful for larger plants especially for waste biological sludges.

operation

Aerobic digestion is a completely mixed activated sludge system with either batch or continuous flow input. The contents of the digestor are aerated for a period of 12 to 22 days depending on the type of sludge. As aeration takes place the organisms consume the food. The food supply decreases and the organisms begin to digest their own cell tissues for energy. The organisms convert this cell tissue to carbon dioxide, water and ammonia. The ammonia is subsequently converted to nitrate as the digestion proceeds. The solids are then separated from the liquid for disposal desired. Solids, after adequate aerobic digestion, usually dewater easily and do not cause odor problems.

design differences

There are some design variations among aerobic digestion systems. Current practice varies according to whether or not the separate sedimentation tank shown in Figure IV-1 is used. Some designs use a batch-type system, where the sludge is aerated and mixed for a number of days, settled without mixing, and sludge and supernatant removed all in the same tank. Aerobic digesters often use rectangular aeration tanks and mechanical or diffused aeration systems.

high purity oxygen

Recently high purity oxygen (95 to 97 percent) aeration has been used for aerobic digesters. In some cases oxygen from atmospheric air (21 percent) cannot be dissolved into the digesting sludge fast enough to meet the requirements of the biological reaction. High purity oxygen can dissolve in sludge nearly five times as fast as oxygen from the air and permits a more concentrated sludge feed to the digester. High purity oxygen digesters are covered or baffled to prevent a high loss of oxygen to the atmosphere.

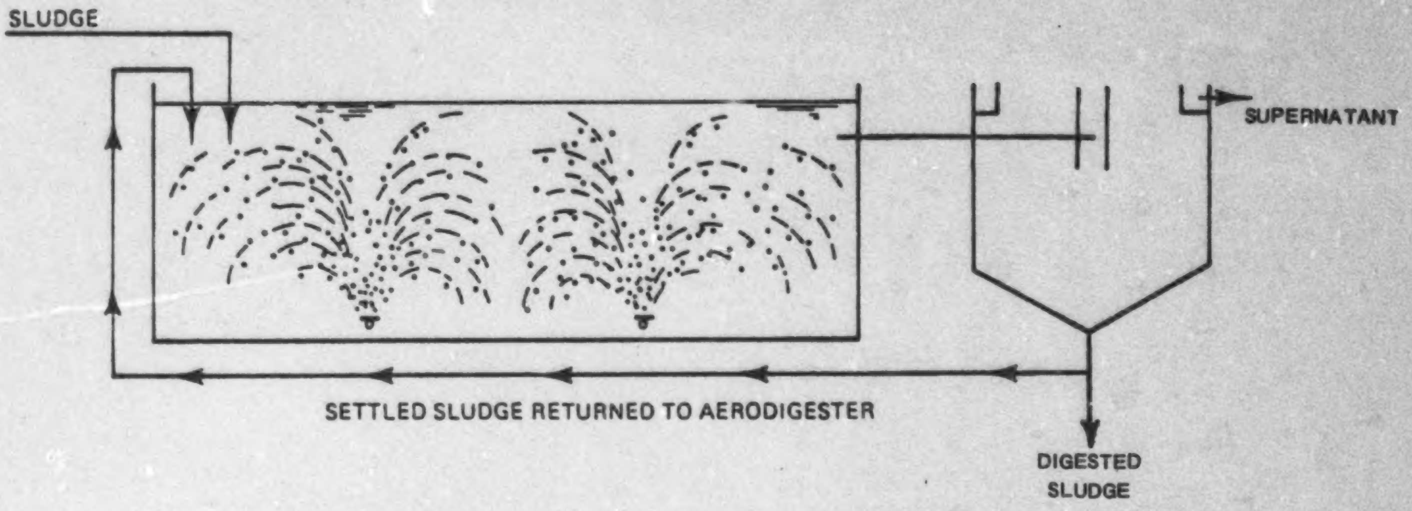

SLUDGE
SUPERNATANT
SETTLED SLUDGE RETURNED TO AERODIGESTER
DIGESTED SLUDGE

Figure IV-1. Schematic of aerobic digestion system.

supernatant return to process

Supernatant from the digestion process is returned to either the primary or the secondary treatment process and normally causes no problem to process operation. The respective treatment process must be capable of handling the additional hydraulic flow resulting from the return of supernatant.

TYPICAL DESIGN CRITERIA & PERFORMANCE

Typical design criteria are shown in "Process Design Manual for Sludge Treatment and Disposal",(EPA 625/1-74-016) and in Table IV-1 (see following page).

Current practice is to provide about 15 days of detention time for the digestion of waste biological sludge and about 20 days when primary sludge is included. Loadings vary from 0.1 to 0.2 pounds of volatile suspended solids (VSS) per cubic foot per day. A 40 to 50 percent reduction in volatile suspended solids content is normally obtained. The supernatant may contain as little as 10 to 30 mg/l BOD, 10 mg/l ammonia nitrogen, and from 50 to 100 mg/l nitrate nitrogen. When nitrification occurs, both pH and alkalinity are reduced.

STAFFING REQUIREMENTS

Labor requirements for operation and maintenance of aerobic digesters are shown in Table IV-2. The requirements are based on plant design flow and include removal of sludge to the next unit process.

TABLE IV-2. AEROBIC DIGESTION LABOR REQUIREMENTS

Plant design flow, mgd	Labor, hr/yr		
	Operation	Maintenance	Total
0.5	100	20	120
1	160	30	190
2	260	50	310
5	500	100	600
10	800	160	960
25	1,500	300	1,800

TABLE IV-1. AEROBIC DIGESTION DESIGN PARAMETERS

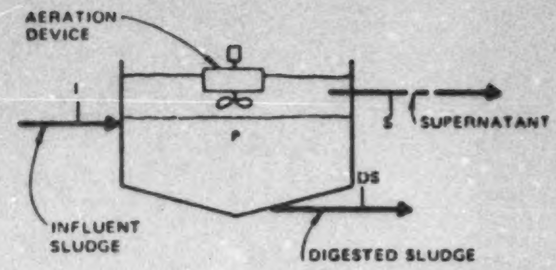
Parameter	Value	Remarks
Solids retention time, days	10-15[a]	Depending on temperature, type of sludge, etc.
Solids retention time, days	15-20[b]	
Volume allowance, cu ft/capita	3-4	
VSS loading, pcf/day	0.024-0.14	Depending on temperature, type of sludge, etc.
Air requirements Diffuser system, cfm/1,000 cu ft	20-35[a]	Enough to keep the solids in suspension and maintain a DO between 1-2 mg/l.
Diffuser system, cfm/1,000 cu ft	>60[b]	
Mechanical system, hp/1,000 cu ft	1.0-1.25	This level is governed by mixing requirements. Most mechanical aerators in aerobic digesters require bottom mixers for solids concentration greater than 8,000 mg/l, especially if deep tanks (>12 feet) are used.
Minimum DO, mg/l	1.0-2.0	
Temperature, °C	>15	If sludge temperatures are lower than 15°C, additional detention time should be provided so that digestion will occur at the lower biological reaction rates.
VSS reduction, percent	35-50	
Tank design		Aerobic digestion tanks are open and generally require no special heat transfer equipment or insulation. For small treatment systems (0.1 mgd), the tank design should be flexible enough so that the digester tank can also act as a sludge thickening unit. If thickening is to be utilized in the aeration tank, sock type diffusers should be used to minimize clogging.
Power requirement, BHP/10,000 Population Equivalent	8-10	

[a] Excess activated sludge alone.

[b] Primary and excess activated sludge, or primary sludge alone.

MONITORING

	TEST FREQUENCY	LOCATION OF SAMPLE	METHOD OF SAMPLE	REASON FOR TEST
TEMPERATURE	1/D	P	G	H
pH	1/D	P	G	H
TOTAL SOLIDS	2/W	I DS	G	H
TOTAL VOLATILE SOLIDS	2/W	I DS	G	H
DO	3/W	P	G	P
SETTLEABLE SOLIDS	3/W	P	G	H
pH	(1)	S	G	H
SUSPENDED SOLIDS	(1)	S	G	H
BOD	(1)	S	G	P(2)
ALKALINITY	2/W	P	G	H


AERATION DEVICE
I
P
S
SUPERNATANT
DS
INFLUENT SLUDGE
DIGESTED SLUDGE

A. TEST FREQUENCY

D = DAY
W = WEEK

B. LOCATION OF SAMPLE

I = INFLUENT
DS = DIGESTED SLUDGE
S = SUPERNATANT
P = PROCESS

C. METHOD OF SAMPLE

G = GRAB SAMPLE

D. REASON FOR TEST

H = HISTORICAL KNOWLEDGE
P = PROCESS CONTROL

E. FOOTNOTES:

1. WHEN DRAW OFF SUPERNATANT.
2. FOR CONTROL OF PROCESS RECEIVING THIS FLOW.

NORMAL OPERATING PROCEDURES

Startup

1. Open digester influent valve or gate and begin filling digester.

2. When diffusers are covered start the air blowers. If mechanical aeration is used, start when the appropriate liquid level is reached.

Routine Operations

Aerobic digestion is, for the most part, a self-regulating process. The exception is when the process is overloaded or the equipment is inoperative.

1. Inspect system twice per shift.

2. Take samples as outlined in MONITORING Section.

3. Aerobic digesters may be operated in continuous or batch flow modes.

    a. Continuous flow, like the operation of a conventional activated sludge aeration tank and as shown in Figure IV-1. A portion of the digested solids are recycled and a portion are removed.

    b. Batch flow, where the digester is operated according to the procedure in the following paragraph.

4. The normal operating procedures for a batch flow digester are as follows:

    a. Fill digester and aerate for the time outlined under CONTROL CONSIDERATIONS.

    b. Turn off aeration equipment and allow the solids to settle. This solid-liquid separation should be limited to three or four hours to avoid clogging of the air diffuser equipment.

    c. Remove as much supernatant as possible. Sample as outlined in MONITORING Section.

    d. Remove the thickened, digested sludge. Sample as outlined in MONITORING Section.

    e. Add new sludge to the digester.

    f. Turn on aeration equipment.

Shutdown

1. Shut off aeration.
2. Decant as much supernatant as possible.
3. Draw off the thickened sludge.
4. Wash down tank and aerators.
5. Drain the digester of its final contents.

CONTROL CONSIDERATIONS

Physical Control

In most plants the aerobic digester is operated as a self-regulating process with very little process control required.

dissolved oxygen

If the digester is equipped with a dissolved oxygen (DO) meter, the aerators should be adjusted so that the DO level is maintained between 1 and 2 mg/l for efficient operation. It has also been found that the digested sludge dewaters best if the DO level is maintained within this range.

batch feed

For batch-feed digesters, sludge should be added, relatively uniform amounts daily, if possible. The volume and concentration of sludge added each day should be as uniform as possible. Sludge settling and drawoff may be performed once a week, while sludge addition or feed is practiced daily. In this way the sludge volume in the digester will increase each day until the next decanting and drawoff period.

continuous feed

The rate of sludge return from the settling basin to the aeration basin of continuous feed digesters must be adjusted in the same manner as for activated sludge treatment. This return flow should be between 20 and 50 percent of the sludge flow to the aeration basin.

Process Control

mixing

Mixing is very important in the operation of aerobic digesters. The solids must be well mixed to provide contact between the organisms and the food supply. Mixing is usually accomplished by the aeration system, however, mechanical mixers or mechanical aerators operating at lower power requirements may be used to help in mixing. In many cases, floating aerators are used because the operational water level in the digester varies from time to time.

inspection

The digester should be inspected once per shift for proper operation of aeration equipment and pumps. The contents of the tank should be well mixed and relatively free of odors.

odors

The aerobic digester should not produce detectable odors. Odors will be produced if the sludge becomes septic. This indicates poor aeration and/or poor mixing.

sampling

Sampling should be performed as outlined under MONITORING. These samples may be obtained through valves provided in the digester piping. If sampling points are not provided, it may be necessary to obtain samples directly from the digester contents.

analysis

Samples should be analyzed according to procedures specified in Standard Methods.

The two major variables that effect the rate of aerobic digestion are temperature, and solids retention time.

temperature

The rate of a biological reaction will increase as the temperature increases. A rule of thumb is that the reaction rate doubles for each 10°C rise in temperature. Although this beneficial temperature effect has been observed in many bench studies, actual aerobic digestion plant experience has not supported fully this rule of thumb. Because of long detention times and tank sizes, aerobic digestion is satisfactory at most ambient temperatures. However, the energy released by the process can cause temperatures to rise if the aerobic digester is covered.

The solids retention time (SRT) is defined as the average length of time that the solids are retained in the process. For continuous feed systems this is:

$$\frac{\text{total mass of solids in digester}}{\text{mass of solids wasted/day}}$$

For a batch feed digester this is:

$$\frac{\text{average mass of the solids in digester during batch}}{\text{(mass of solids wasted from batch)(number of days in batch)}}$$

Some recommended SRT values are given below for operation at 20°C.

Sludge type	SRT, days
Activated only	12-16
Activated with no primary settling	16-18
Primary plus activated or trickling filter sludge	18-22

Carbon dioxide and the nitrate ion, two products of aerobic digestion, tend to lower the pH of the digester. The pH decrease depends on the stability of the bacteria and the buffering capacity of the water which vary for each treatment plant situation. In some cases, the decline in pH may be enough that readjustment of pH is necessary. If readjustment is necessary, an alkaline liquid or slurry such as sodium hydroxide, sodium bicarbonate, or lime can be added to the digester as required. Removing the CO_2 from the gas above a closed top digester may also help to reduce the drop in pH.

EMERGENCY OPERATING PROCEDURES

Loss of Power

Short power interruptions should not greatly affect the aerobic digestion process. Although electrical equipment will not operate, the digestion process will be satisfactory if power is regained within about 30 minutes to several hours. If power is unavailable for longer periods, septic conditions may develop. Septic odors can be overcome by adding chlorine, however, this will affect the digestion process.

Loss of Other Treatment Units

Most sludges are thickened prior to aerobic digestion. The loss of the thickener means that a more dilute sludge (more water) will be sent to the digester. This may be partially overcome by decanting supernatant from the digester more frequently.

The loss of other processes to which the digested solids are pumped may create a solids storage problem. The sludge may be left in the digester for a few days longer than the required retention time, however, in case of a prolonged problem it may be necessary to haul sludge to another treatment facility or disposal area.

COMMON DESIGN SHORTCOMINGS

Shortcoming	Solution
1. No provisions for pH adjustment and low pH occurs in aerobic digester.	1. Install system to feed sodium bicarbonate to digester influent or alkaline materials such as sodium hydroxide or lime to digester.
2. Air diffusers plug frequently.	2. Replace diffusers with a type with larger openings. This may require additional blower capacity due to lower oxygen

Shortcoming		Solution	
2.	continued	2.	transfer efficiency. Install mechanical aeration equipment.
3.	Solids depositing and accumulating in digester due to marginal mixing capabilities.	3.	Increase mixing in digester by increasing aeration or mixing.

TROUBLESHOOTING GUIDE

AEROBIC DIGESTION

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Excessive foaming.	1a. Organic overload.	1a. Organic load.	1a. (1) Reduce feed rate (2) Increase solids in digester by decanting and recycling solids.
	1b. Excessive aeration.	1b. Dissolved oxygen.	1b. Reduce aeration rate.
2. Low dissolved oxygen.	2a. Diffusers clogging.	2a. Decant digester, withdraw sludge and inspect diffusers.	2a. Clean diffusers or replace with coarse bubble diffusers or sock-type devices.
	2b. Liquid level not proper for mechanical aeration.	2b. Check equipment specifications.	2b. Establish proper liquid level.
	2c. Blower malfunction.	2c. Air delivery rate, pipeline pressure, valving.	2c. Repair pipe leaks, set valves in proper position, repair blower.
	2d. Organic overload.	2d. (See 1a)	
3. Sludge has objectionable odor.	3a. Inadequate SRT.	3a. SRT.	3a. (See 1a).
	3b. Inadequate aeration.	3b. DO should exceed 1 mg/l.	3b. Increase aeration or reduce feed rate.
4. Ice formation damages mechanical aerators.	4a. Extended freezing weather.	4a. Check digester surface for ice block information.	4. Break and remove ice before it causes damage.
5. pH in digester has dropped to undesirable level (below 6.0-6.5).	5a. Nitrification is occurring and wastewater alkalinity is low.	5a. pH of supernatant.	5a. Add sodium bicarbonate to feed sludge or lime or sodium hydroxide to digester.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	5b. In covered digester CO_2 is accumulating in air space and is dissolving into sludge.		5b. Vent and scrub the digester gas.

MAINTENANCE CONSIDERATIONS

The maintenance program for the aerobic digester is very similar to the program for the activated sludge process. Mechanical equipment requiring regular attention includes the aeration system, the mixing and the pumping equipment.

aeration equipment

Air diffusers and tanks should be scheduled for inspection at least once a year. It is common for certain types of fine bubble diffusers to clog over a period of time. Scheduled draining of the tank(s) for inspection and service should be done in the summer if possible.

mechanical equipment

Mixing, pumping, and blower equipment should be inspected annually for worn blades and impellers. Seals, packing, and bearings should be inspected and serviced as recommended in the manufacturer's service manual. Air filters should be serviced at regular intervals.

SAFETY CONSIDERATIONS

The aerobic digestion equipment presents no special hazards, however, general safety considerations should apply. At least two persons should be present when working in areas not protected by handrails. Walkways and work areas should be kept free of grease, oil, leaves and snow. Protective guards and covers must be in place unless mechanical/ electrical equipment is locked out of operation.

REFERENCE MATERIAL

References

1. Standard Methods for the Examination of Water and Wastewater. Americal Public Health Association, 1015 Eighteenth Street, N.W., Washington, D.C. 20036.

2. WPCF Manual of Practice No. 17. (WPCF MOP No. 17), Paints and Protective Coatings for Wastewater Treatment Facilities.

3. WPCF Manual of Practice No. 11, Chapter 19. Operation of Wastewater Treatment Plants, Aerobic Digestion.

Glossary of Terms and Sample Calculations

1. Sludge Concentration is the weight of solids per unit weight of sludge. It can be calculated in percent as follows:

$$\text{Concentration} = \frac{\text{weight of dry sludge solids}}{\text{weight of wet sludge}} \times 100$$

2. Solids Retention Time (SRT) is the average time that the solids remain in the process. For continuous feed systems:

$$\text{SRT} = \frac{\text{Total mass of solids in digester}}{\text{mass of solids wasted/day}}$$

For batch feed systems:

$$\text{SRT} = \frac{\text{average mass of the solids in digester during batch}}{\text{(mass of solids wasted from batch)(number of days in batch)}}$$

As an example assume the following data:

Continuous feed:

Tank volume = 65,000 gal Solids = 2.5%

Wasting rate = 2000 gal/day Solids = 5.0%

$$\text{SRT} = \frac{65{,}000 \times 0.025}{2{,}000 \times 0.05} = 16.3 \text{ days}$$

Batch feed with sludge settling and drawoff once per week:

Sludge volume in digester at beginning of week:	40,000 gal
Sludge volume in digester at end of week:	65,000 gal

Solids = 2.5%

Total of supernatant and settled sludge drawoff:	25,000 gal

Number of days in batch = 7

Average volume of sludge in digester =

$$\frac{40{,}000 + 65{,}000}{2} = 52{,}500$$

$$\text{SRT} = \frac{52{,}500 \times 0.025}{25{,}000 \times 0.025} \times 7 = 15 \text{ days}$$

3. Supernatant is the clarified liquid which forms above the sludge layer during the settling process. The supernatant is decanted from the aerobic digester and returned to the plant.

V

THERMAL TREATMENT

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PROCESS DESCRIPTION

types

There are two basic processes for thermal treatment of sludges. One, wet air oxidation, is the flameless oxidation of sludges at temperatures of 450 to 550°F and pressures of about 1200 psig. The other type, heat treatment, is similar, but carried out at temperatures of 350 to 400°F and pressures of 150 to 300 psig. Wet air oxidation reduces the sludge to an ash and heat treatment improves the dewaterability of the sludge. The lower temperature and pressure heat treatment is more widely used than the oxidation process. The two processes are similar and this manual covers both.

heat treatment process

When the organic sludge is heated, heat causes water to escape from the sludge. Thermal treatment systems release water that is bound within the cell structure of the sludge and thereby improves the dewatering and thickening characteristics of the sludge. The oxidation process further reduces the sludge to ash by wet incineration (oxidation). A typical heat treatment process is shown in Figure V-1 (see following page). Sludge is ground to a controlled particle size and pumped to a pressure of about 300 psi. Compressed air is added to the sludge (wet air oxidation only), the mixture is brought to a temperature of about 350°F by heat exchange with treated sludge and direct steam injection, and then is processed (cooked) in the reactor at the desired temperature and pressure. The hot treated sludge is cooled by heat exchange with the incoming sludge. The treated sludge is settled from the supernatant before the dewatering step. Gases released at the separation step are passed through a catalytic afterburner at 650 to 705°F or deodorized by other means. In some cases these gases have been returned through the diffused air system in the aeration basins for deodorization.

wet air oxidation process

The same basis process is used for wet air oxidation of sludge by operating at higher temperatures (450 to 640°F) and higher pressures (1200 to 1600 psig). The wet air oxidation (WAO) process is based on the fact that any substance capable of burning can be oxidized in the presence of water at temperatures between 250°F and 700°F. Wet air oxidation does not require preliminary dewatering or drying as required by conventional air combustion processes. However, the oxidized ash must be separated from the water by vacuum filtration, centrifugation, or some other solids separation technique.

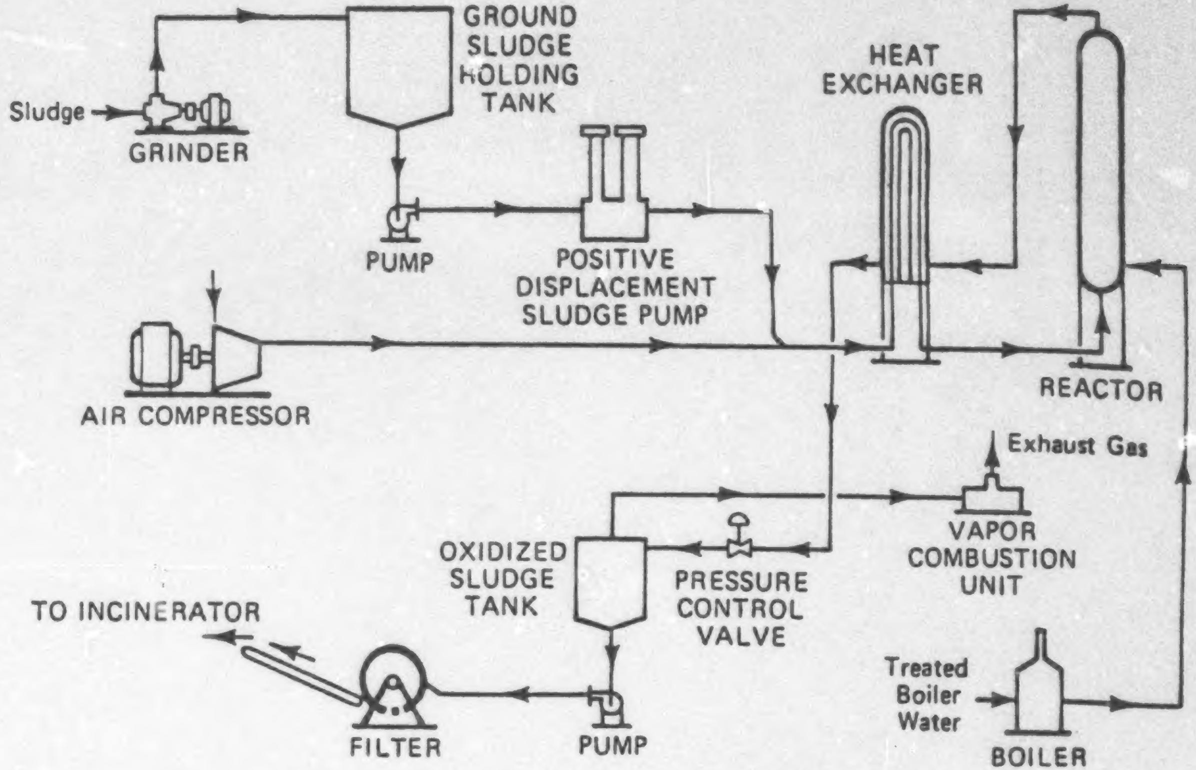

GROUND SLUDGE HOLDING TANK
Sludge
GRINDER
PUMP
POSITIVE DISPLACEMENT SLUDGE PUMP
HEAT EXCHANGER
REACTOR
AIR COMPRESSOR
Exhaust Gas
VAPOR COMBUSTION UNIT
OXIDIZED SLUDGE TANK
PRESSURE CONTROL VALVE
TO INCINERATOR
Treated Boiler Water
FILTER
PUMP
BOILER

Figure V-1. Thermal treatment system schematic.

advantages

An advantage of thermal treatment is that a more readily dewaterable sludge is produced than with chemical conditioning. Dewatered sludge solids of 30 to 40 percent (as opposed to 15 to 20 percent with chemical conditioning) have been achieved with heat treated sludge at relatively high loading rates on the dewatering equipment (2 to 3 times the rates with chemical conditioning). The process also provides effective disinfection of the sludge.

disadvantages

Unfortunately, the heat treatment process ruptures the cell walls of biological organisms, releasing not only the water but some bound organic material; returns to solution some organic material previously converted to particulate form; and creates other fine particulate matter. The breakdown of the biological cells as a result of heat treatment converts these previously particulate cells back to water and fine solids. This aids the dewatering process, but creates a separate problem of treating this highly polluted liquid from the cells. Treatment of this water or liquor requires careful consideration in design of the plant because the organic content of the liquor can be extremely high.

TYPICAL DESIGN CRITERIA & PERFORMANCE

Thermal treatment units are sized based on the anticipated sludge flow rate (gpm). The flow rate determines the detention time in the heat exchanger(s) which is typically 30 to 60 minutes.

The terms used to categorize the degree of wet oxidation - low oxidation, intermediate oxidation, and high oxidation - refer to the degree of reduction in the chemical oxidation demand (COD) of the sludge. Higher temperatures are required to effect higher degrees of oxidation, and the higher temperatures, in turn, require the use of correspondingly higher pressures in order to prevent flashing to steam or burning.

The operating temperature and pressure ranges for the three oxidation categories are given below:

Oxidation category	COD reduction, percent	Temp., °F	Pressure, psi
Low	5	350-400	300-500
Intermediate	40	450	750
High	92-98	675	1,650

With high oxidation the amount of sludge ash is about the same as with air incineration.

STAFFING REQUIREMENTS

Manpower estimates for thermal treatment are shown in Table V-1, and are broken down into operation and maintenance requirements. Operation includes time spent reading and logging process data, controlling and adjusting the various systems and components, and laboratory work. Maintenance includes cleaning and repairing process components, general upkeep of the process area, checking and repairing of controls and instrumentation, and performing preventative maintenance. In some plants these operation and maintenance functions may vary or may overlap.

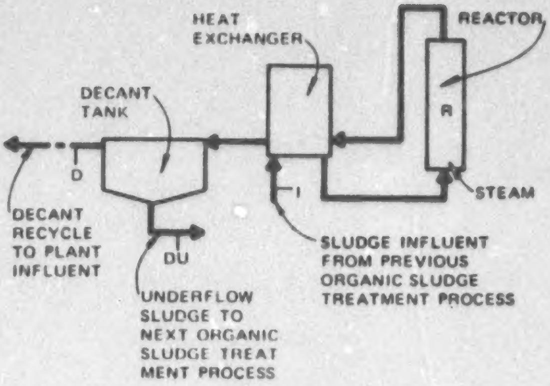
Labor requirements for major overhaul work such as reactor cleaning; pipe and tube replacement; pump, compressor and boiler working parts replacement and other similar items are not included. For this type of work, except in large plants, the skills of contracted specialists would normally be utilized.

TABLE V-1. THERMAL TREATMENT LABOR REQUIREMENTS

Thermal treatment capacity, GPM	Labor, hr/yr Operation	Maintenance	Total
5	4,600	1,200	5,800
10	5,100	1,300	6,400
20	6,000	1,400	7,400
50	8,200	1,900	10,100
100	11,000	2,300	13,300
200	16,000	3,200	19,200
400	22,000	4,300	26,300

MONITORING

SUGGESTED MINIMUM	PLANT SIZE (MGD)	TEST FREQUENCY	LOCATION OF SAMPLE	METHOD OF SAMPLE	REASON FOR TEST
TOTAL SOLIDS	ALL	1/D	I DU	G	P
TEMPERATURE	ALL	Mn	R	Mn	P
pH	ALL	1/D	D	G	H
SUSPENDED SOLIDS	ALL	1/D	D	G	H
BOD	ALL	2/W	D	G	$P^{(1)}$
FLOW	ALL	R	D	R	$P^{(1)}$


HEAT EXCHANGER
REACTOR
DECANT TANK
R
D
I
STEAM
DECANT RECYCLE TO PLANT INFLUENT
DU
SLUDGE INFLUENT FROM PREVIOUS ORGANIC SLUDGE TREATMENT PROCESS
UNDERFLOW SLUDGE TO NEXT ORGANIC SLUDGE TREAT MENT PROCESS

A. TEST FREQUENCY

R = RECORD CONTINUOUSLY
D = DAY
W = WEEK
Mn = MONITOR CONTINUOUSLY

B. LOCATION OF SAMPLE

I - INFLUENT
D - DECANT
R - REACTOR (INCLUDE AS PROCESS TESTING)
DU- DECANT UNDERFLOW

C. METHOD OF SAMPLE

G = GRAB SAMPLE
R = RECORD CONTINUOUSLY
Mn = MONITOR CONTINUOUSLY

D. REASON FOR TEST

H = HISTORICAL KNOWLEDGE
P = PROCESS CONTROL

E. FOOTNOTES:

1. FOR CONTROL OF PROCESS RECEIVING THIS FLOW.

NORMAL OPERATING PROCEDURES

General

The procedures for starting heat treatment equipment vary somewhat depending on the equipment manufacturer and the other treatment at the plant. One characteristic common to all heat treatment units is that the operating procedures are sequential and must be systematically followed with no step omitted. It is recommended that the operator read and understand the various instruction manuals supplied with the equipment at his plant before attempting any operational procedure. With this in mind, the following generalized instructions are only a guideline. A manufacturer's representative should always be present during the initial process startup.

Cold Startup

This procedure is used when the system is cold, drained and depressurized.

1. Review cold startup valve positioning checklist.
2. Review cold startup instrumentation setpoint checklist.
3. Start high pressure pump (at specified flow rate) and operate on water.
4. Start process air compressor.
5. Pressurize the system.
6. Start the boiler (steam supply).
7. Start grinder.
8. Switch pumping from water to sludge.
9. Increase sludge flow to full rate.
10. Prepare scrubber and fume incinerator.
11. Start the rake mechanism in the oxidized sludge storage tank.
12. Start the treated sludge dewatering system.

Hot Startup

This procedure is used when the reactor is filled with hot sludge and pressurized (commonly called a "bottled" reactor), and the balance of the system is depressurized and cool.

1. Review hot startup valve positioning checklist.
2. Review hot startup instrumentation setpoint checklist.
3. Prepare scrubber and fume incinerator.
4. Start the rake mechanism in the oxidized sludge storage tank.
5. Start the high pressure pump (at specified flow rate) and operate on water.
6. Start process air compressor.
7. Pressurize the system.
8. Start the boiler.
9. Unbottle the reactor.
10. Start grinder.
11. Switch from water to sludge.
12. Increase sludge flow to full rate.
13. Start the treated sludge dewatering system.

Routine Operations

Thermal treatment systems should always have an operator in attendance when they are running. The lead operator should be machinery oriented and able to do routine preventive maintenance.

Each hour, the operator should:

1. Record all instrument readings on log sheet. Compare with previous readings and investigate any unexplained changes. Temperature or pressure deviations above or below setpoint may be the first indication of trouble.
2. Adjust pumping system as necessary to maintain desired sludge flow rate.
3. Adjust oxidation system as necessary to maintain desired temperatures.
4. Examine each operating piece of equipment. Check

lubrication, cooling water, operating temperatures, leakage, sound, and vibration. Any unit which appears to be operating abnormally should be closely watched and the cause of the abnormal operation determined and corrected without delay. The operator should not hesitate to shut down the system if operating irregularities persist without obvious cause, or become progressively worse.

5. Take samples as required.

Cold Shutdown

This procedure is used to remove the system from service where all components are to be depressurized and cooled including the reactor.

1. Switch from sludge to water.
2. Close steam block valve to reactor.
3. Shut down the boiler.
4. Clean pressure control valves.
5. Reduce system pressure.
6. Bottle the reactor.
7. Depressurize the heat exchanger(s).
8. Blow down the reactor.
9. Shut down the high pressure pump.
10. Pressurize the reactor.
11. Shut down the air compressor.
12. Blow down the reactor (second blowdown).
13. Shut down the treated sludge dewatering equipment.
14. Shut down the rake mechanism in the oxidized sludge storage tank.
15. Shut down the scrubber-fume incinerator.
16. Shut down the instrument air compressor and air dryer.

Hot Shutdown

This procedure is used to remove the system from service, but maintains the reactor in a bottled condition (filled and pressurized) which simplifies the startup procedure.

1. Switch from sludge to water.
2. Reduce reactor pressure.
3. Bottle the reactor.
4. Shut down the boiler.
5. Raise system pressure.
6. Clean the pressure control valves.
7. Backwash downcomber line.
8. Shut down the process air compressor.
9. Shut down the high pressure pump.
10. Depressurize the system.
11. Shut down the treated sludge dewatering equipment.
12. Shut down the rake mechanism in the oxidized sludge storage tank.
13. Shut down the scrubber-fume incinerator.
14. Shut down the instrument air compressor and dryer.

CONTROL CONSIDERATIONS

Physical Control

Four important physical variables control the performance of wet oxidation units: temperature, air supply, pressure, and feed solids concentration. Controls are normally provided for controlling reactor temperature, pressure, and the air supply.

Process Control

The extent and rate of sludge solids oxidation are determined by the reactor pressure and temperature. Much higher degrees of oxidation and shorter reaction times are possible at higher pressures and temperatures. The reactor temperature and pressure affect the quality of the recycle *temperature*

water (liquor) and the dewaterability of the oxidized sludge. Reaction temperature should be kept as low as possible, consistent with adequate conditioning of the sludge. Higher temperatures cause more complete breakdown of the sludge particles, releasing more cell water and thus releasing more BOD into solution. Higher temperatures do provide a treated sludge which dewaters readily, but at great sacrifice because of the poorer quality of the recycle liquor.

air flow

As with conventional incinerators, an external supply of oxygen (air) is required to attain nearly complete oxidation. The air requirement for the wet oxidation process is determined by the heat value of the sludge being oxidized, and by the degree of oxidation desired. Thermal efficiency and fuel requirements are functions of air input, so it is important that the air flow not be higher than needed. Because the input air becomes saturated with steam from contact with the liquid in the reactor, it is also important to control the air flow to prevent excessive loss of water from the reactor.

holding time

Increasing the holding time in the thermal reactor will increase the breakdown of the sludge cells and degrade the fibrous material. The effect is that the quality of the recycle water will be poorer and the treated sludge will not dewater as well. For example, in low oxidation at 350 to 400°F, the color of the recycle liquor increases from 2,150 units for a reaction time of 3 minutes, to 3,800 units at 15 minutes, to 5,500 units at 30 minutes.

The recycle liquor can be very difficult to treat, offensive smelling, and can upset plant treatment processes; therefore it must be considered carefully in operating thermal treatment processes. Typical recycle liquor characteristics are as follows.

recycle liquor

Substances in strong liquor	Concentration range, mg/1 (except as shown)
TSS	100 - 20,000
COD	100 - 17,000
BOD	3,000 - 15,000
NH_3-N	400 - 1,700
Phosphorus	20 - 150
Color	1,000 - 6,000 units

These high concentrations illustrate the potential impact that recycle of the liquor can have on the wastewater treatment processes. It is important that the operator recognize the significance of the recycle load in the management of the overall plant operation.

time and temperature

An equal degree of filterability and settleability can, within limits, be accomplished by various combinations of time and temperature. For instance high temperature and short reaction time as compared to lower temperature and longer reaction time. Longer reaction time at low temperature treatment is usually the most economical. Overcooking (various combinations of high temperatures and long reaction times) actually breaks down the fibrous material itself (as compared to simply releasing the cell water) and produces a more difficult to dewater treated sludge.

pH

The pH at which sludges are heat treated has an effect on the dewaterability of the treated sludge. Treatment at lower pH produces a more dewaterable treated sludge, but corrosion problems are increased.

other considerations

Cooling of heat treated sludges prior to atmospheric exposure can reduce, but will not eliminate odor problems. Increasing the solids content of the sludge feed to the heat treatment process decreases operating costs, but increases the content of dissolved COD, nitrogen, and phosphorus in the recycle liquor and may reduce the dewaterability of the treated sludge.

EMERGENCY OPERATING PROCEDURES

Loss of Power

In the event of a prolonged failure or one of undeterminable duration, the following procedure should be used.

Isolate (bottle) the reactor. Immediately thereafter, reduce the pressure slowly with the pressure control valve to transfer as much of the contents of the heat exchangers as possible to the decant tank. This is to prevent blockage from solids that might bake on the sides of the heat exchanger tubes or settle into the "U" bends.

The reason for doing this very soon after the power failure is that the pressure in the instrument air receiver will dissipate slowly and will be adequate for performing this shutdown procedure for only a limited time until the air pressure is lost.

Loss of Other Treatment Units

The loss of other treatment units should not greatly affect the operation of the thermal treatment unit. Performance, however, may be affected if the incoming solids concentration changes.

COMMON DESIGN SHORTCOMINGS

Shortcoming	Solution
1. Effects of recycled liquors on wastewater treatment process were not adequately considered and plant is upset.	1a. Store liquors and recycle during low flow night time conditions.
	1b. Install separate treatment system for liquors before they are recycled (review with consultant).
2. Lack of or inadequate equipment installed for deodorization of off-gases from decant tanks, thickeners, or dewatering system.	2a. Temporary solutions may include addition of hydrogen peroxide to open tanks or use of masking chemicals.
	2b. Install adequate deodorization equipment (review with consultant).
	2c. Collect these off gases and pipe back to the diffused air system in the aeration basins.
3. Backup support systems (boiler, feed pumps, grinders, air compressors, etc) not provided.	3. Install backup components.
4. High temperatures and presence of calcium, sulfates, or chlorides in the sludge creates excessive scaling & corrosion in heat exchangers & reaction vessels, and piping.	4. Use 316 stainless steel or Titanium for materials of construction.

TROUBLESHOOTING GUIDE

THERMAL TREATMENT

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Odors	1a. Odors being released in decant tanks, thickeners, vacuum pump exhaust or in dewatering.		1a. (1) Cover units, collect air and deodorize it before release by use of incineration, adsorption, or scrubbing. (2) Cover open tank surface with small floating plastic balls to reduce evaporation and odor loss.
	1b. Odors being released when recycle liquors enter wastewater treatment tanks.		1b. Pre-aerate liquors in covered tank and deodorize off-gases.
2. Raw sludge grinder requires very frequent maintenance.	2. Excessive grit in raw sludge.	2. Operation of raw sludge degritting system and raw sewage grit removal.	2. Maintain and properly operate the raw sludge and raw sewage degritting systems.
3. Scaling of heat exchangers.	3a. Calcium sulfate deposits.	3a. Efficiency of heat transfer - difficult to maintain reactor temperatures.	3a. Provide acid wash, in accordance with manufacturer's instructions.
	3b. Operating temperatures too high - causing baking of solids.		3b. Operate reactor at temperatures below 390°F for heat conditioning of sludge.
			3c. Use hydraulically driven cleaning bullet to clean inner tubes.
4. Heat treatment system down time is substantial.	4. Inadequate operation & maintenance skills.		4. Contract for maintenance of system & institute training program for operators.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
5. Grinder has shut down.	5a. Loss of seal water.	5a. Seal water supply - are valves open.	5a. Establish flow of seal water.
	5b. Grinder has jammed.	5b. Is grinder motor reversing automatically when overloaded.	5b. Remove obstruction.
6. Feed pumps are overheating.	6a. Inadequate lubrication.	6a. Oil levels.	6a. Lubricate pumps.
	6b. Cooling water supply inadequate.	6b. Cooling water.	6b. Establish adequate flow of cooling water.
7. Steam use is high.	7. Sludge concentration to heat treatment unit is low.	7. Sludge concentration.	7. Operate thickener to maintain 6 percent solids if possible; 3 percent minimum.
8. Solids dewater poorly.	8a. Anaerobic digestion prior to heat treatment.		8a. Discontinue anaerobic digestion of sludge to be heat treated.
	8b. Temperatures not maintained high enough.	8b. Reactor temperatures.	8b. Temperature should be at least 350°F.
9. High system pressure.	9a. Blockage in reactor.	9a. (1) If relief valves are blowing, shut down unit. (2) If relief valves are not blowing, blockage was temporary.	9a. (1) Remove blockage. (2) Check pressures and temperatures to note any discrepancies from normal.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	9b. Pressure controller set too high.	9b. Pressure controller setting.	9b. Reduce set point on pressure controller.
	9c. Block valve closed.	9c. Block valve.	9c. Check system for proper valving.
10. Feed pumps not pumping adequate flow.	10a. Improper control setting.	10a. Control setting.	10a. Adjust control setting.
	10b. Leakage or plugging in product check valves.	10b. Inspect check valves	10b. Repair or replace check valves.
	10c. Air trapped in pump cylinders.		10c. Bleed off air.
11. System pressure is dropping.	11a. Pressure controller set too low.	11a. Setting on pressure controller.	11a. Set pressure controller at proper valve.
	11b. Pressure control valve trim is eroded.	11b. Inspect valve.	11b. Replace valve.
12. Oxidation temperature is rising.	12a. Inlet temperature too high.	12a. Should not exceed 310°F for sludge conditioning.	12a. Reduce temperature by diluting incoming sludge with water.
	12b. Sludge feed rate is too slow.	12b. Operation of sludge feed pumps and feed rate.	12b. Increase sludge feed rate.
	12c. Improper control setting.	12c. Temperature control.	12c. Appropriately adjust control setting.
	12d. Pump stopped or slowed.	12d. Pump operation.	12d. Start pump and/or increase rate.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	12e. Volatile matter such as gas or oil being pumped through the system.		12e. Switch from sludge to water and stop the process air compressor.
	12f. Pneumatic steam valve not functioning properly.	12f. Valve operation.	12f. Repair malfunctioning valve.
13. Oxidation temperature is falling.	13a. Heat exchanger fouled.	(see item 3)	
	13b. Reactor inlet temperature is too low, because of low density sludge.	13b. Should be at least 280°F.	13b. Reduce dilution of incoming sludge.
	13c. High flow rate being pumped through system.	13c. System flow rate.	13c. Reduce flow rate at high pressure pump(s).
	13d. Improper temperature control setting.	13d. Temperature control setting.	13d. Appropriately adjust.
	13e. Pneumatic steam valve not functioning properly.	13e. Steam valve.	13e. Repair malfunctioning valve.
	13f. No signal air to the temperature control valve.		13f. Check instrument air supply.
	13g. Boiler not functioning properly.	13g. Boiler operation.	13g. Consult boiler manufacturer's instruction manual for corrective action.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
14. Scoring of air compressor cylinder walls and pistons.	14a. Carbon or other foreign material in compression cylinder.	14a. Visual inspection.	14a. Maintain compressor system to avoid material from entering system.
15. Filter cake difficult to feed into incinerator.	15a. Filter cake too dry.		15a. Reduce temperature (and pressure) of the treatment system.
16. Low system pressure.	16a. High pressure pump and/or process air compressor and/or boiler stopped.		
	16b. Intake filter clogged.	16b. Inspect filter for clogging.	16b. Clean or replace filter.
	16c. Pressure controller set too low.	16c. Pressure controller setting.	16c. Increase set point on pressure controller.
	16d. Any of the blowdown valves may be partially opened.	16d. Valves.	16d. Check compressor valving.
	16e. Leaking interstage trap.		16e. Check trap for proper operation.
	16f. Slipping drive belts.	16f. Drive belt slippage.	16f. Adjust belt tension.
17. High temperature.	17a. Inadequate water flow.	17a. Water flow.	17a. Adjust water flow.
	17b. Leaking cylinder valves.	17b. Cylinder valves.	17b. Repair and/or clean or replace.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	17c. Intercooler and/or jackets plugged.	17c. Visual inspection.	17c. Clean intercooler and/or replace.
	17d. No flow from the force feed lubricators.	17d. (1) Low oil level. (2) Malfunctioning lubricator. (3) Loose or worn belt.	17d. (1) Add oil. (2) Repair lubricator. (3) Tighten loose belt, or replace if worn.
18. Air compressor safety valve receiving.	18a. Pressure controller set too high.	18a. All system pressures appear high.	18a. Reduce set point on controller.
	18b. No signal air pressure to PCVs.		18b. Check instrument air supply.
	18c. One or more block valves in the system are closed.	18c. Valves closed.	18c. Check system for proper valving.
	18d. Plugged pressure control valve (PCV).	18d. Visual inspection.	18d. Switch to standby PCV and clean plugged valve.

MAINTENANCE CONSIDERATIONS

Thermal treatment unit maintenance must consider both components and system. Component considerations consist of routine inspection, preventative maintenance, and lubrication schedules. The manual supplied with the equipment should be consulted for this information. It is suggested that records be kept to determine whether the maintenance program is being followed. These records should include the inspection dates and service performed.

component maintenance

System maintenance consists of a set of routine cleaning procedures for removing scale buildup from system components and piping. This usually involves periodic washdown with 5 percent solution of nitric acid in water. System components requiring this type of cleaning usually include the heat exchanger, the reactor, and the oxidized sludge decant tank. This maintenance must be performed on a regular schedule to maintain satisfactory operation. Instructions for this type of cleaning are specific to the thermal treatment system in question and depend on valving, piping and type of system components.

system maintenance

An example of a cleaning sequence for a heat exchanger is shown below:

1. Review heat exchanger cleaning valve positioning checklist.
2. Start the solvent pump.
3. Flush the heat exchangers with water.
4. Fill the solvent tank.
5. Start the boiler.
6. Heat the water in the solvent tank.
7. Shut down the boiler.
8. Add nitric acid to the solvent tank.
9. Circulate the acid solution.
10. Dispose of the acid, generally, it must be neutralized.
11. Stop the solvent pump.
12. Start the oxidation unit as per hot startup instructions.

heat exchanger cleaning

The need for heat exchanger cleaning is indicated by an increasing temperature differential between the reactor inlet and outlet, and an increasing pressure drop through the system.

pipe cleaning

The need for cleaning of piping is usually determined by opening the pipe at regular intervals and performing visual inspections. One manufacturer recommends a solvent wash when the scale buildup exceeds 1/8 inch. Pipeline cleaning pigs may also be effective for some cleaning applications.

reactor cleaning

In addition to the above routine cleaning, a thorough check for scale buildup inside the reactor should be accomplished annually. If a scale problem is evident and the acid cleaning procedures are ineffective, it may be necessary to remove the scale mechanically. This may be accomplished by an air-driven turbine cutting tool or a high pressure water blast. Local companies are usually available with the equipment necessary for this type of cleaning.

pressure test

An annual pressure check, usually a hydrostatic test, following the manufacturer's instructions, should be accomplished to insure the integrity of the pressure piping and fittings.

SAFETY CONSIDERATIONS

Safety is an important consideration when operating thermal treatment processes. Observation of temperatures and pressures and visual checks of operating machinery are the most important aspects of safe operation.

1. If at any time during operation the system temperatures are abnormally high, stop the air compressor and switch from sludge to water. Abnormally high temperatures are shown in the manufacturer's manuals.

2. Any inspection or cleaning should be done with that section of the system completely depressurized. Liquids under pressure can cause serious harm to personnel if suddenly discharged.

3. Proper protective equipment should be worn during inspection and cleaning per manufacturer's recommendations.

4. Observe proper handling procedures when using acid solutions for cleaning. Recommended safety procedures should be obtained from the supplier and implemented prior to handling of any acid in the plant.

5. Vessels should be well ventilated and completely isolated before entering. Never enter a vessel without a lift line held by someone outside the vessel and a reliable source of air inside the tank.

6. Carbon coatings on high pressure air compressor discharge valves indicate too much oil is being used to lubricate the cylinder. Failure to correct this could result in fires at the discharge of these cylinders.

7. Motor circuit disconnects should be locked open before working on any machine.

8. Belt driven equipment should not be operated without safety guards.

9. Follow State and Federal safety codes for this type of equipment.

10. Wear proper masks when working around the supernatant and liquor because of the gases and odors.

REFERENCE MATERIAL

References

1. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, 1015 Eighteenth Street, N.W., Washington, D.C. 20036.

2. WPCF Manual of Practice No. 17 (WPCF MOP No. 17), Paints and Protective Coatings for Wastewater Treatment Facilities.

Glossary of Terms and Sample Calculations

1. Recycle liquor or "cooking liquor" is the liquid removed from the sludge by decanting or thickening. Generally, the liquor is odorous and difficult to treat.

2. Off gases are the gases released from various open tanks in the thermal treatment process. These gases are odorous and must be collected and treated prior to discharge to the atmosphere.

3. COD (chemical oxygen demand) is an important, rapidly measured parameter for determining the oxygen equivalent of that portion of the organic and inorganic matter in a sample that is susceptible to oxidation by a strong chemical oxidant. Thus, COD is the oxygen consuming organic and inorganic matter present in wastewater.

4. BOD or biochemical oxygen demand, is the amount of oxygen required for the biological oxidation of degradable organic content in a liquid, during a specified time, and at a specified temperature. Results of the standard test assessing wastewater strength usually are expressed in mg/l as 5-day 20°C BOD.

VI

LIME TREATMENT

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PROCESS DESCRIPTION

process

The lime stabilization process can be used to treat raw primary, waste activated, septage and anaerobically digested sludges. The process involves mixing a large enough quantity of lime with the sludge to increase the pH of the mixture to 12 or more. This normally reduces bacterial hazards and odor to a negligible value, improves vacuum filter performance and provides satisfactory means of stabilizing the sludge prior to ultimate disposal.

operation

Lime slurry is normally added to the sludge in a mixing tank. Mixing is accomplished by either diffused air or mechanical agitators. Enough lime is added to increase the sludge pH to the desired level. After this initial mixing the lime treated sludge is transferred to a contactor vessel. Mixing is continued in the contactor and additional lime is added, if necessary, to maintain the desired pH. The sludge remains in the contactor for a specified time period, typically 30 minutes. The treated sludge is thickened and stored or disposed of immediately.

Differences between various designs may affect operation at individual plants. For example, the mixing, 30 minute contact time and thickening required for this process may all occur in one tank. In general, the operation and maintenance suggestions in this section apply to all systems, however, the operator should note the particular requirements of the equipment at his plant.

A typical process flowsheet for lime stabilization is shown in Figure VI-1 (see following page).

supernatant return to process

Sludge supernatant is usually returned to either the primary or the secondary treatment process and normally causes no problem to process operation. The respective treatment process must be able to handle the increase in flow resulting from the return of supernatant.

TYPICAL DESIGN CRITERIA AND PERFORMANCE

Lime facilities for sludge stabilization are sized on the basis of the daily sludge volume treated. The amount of lime used varies but can be estimated using Table VI-1 (see following page). Lime handling facilities are then based on the quantity of lime needed for treatment.

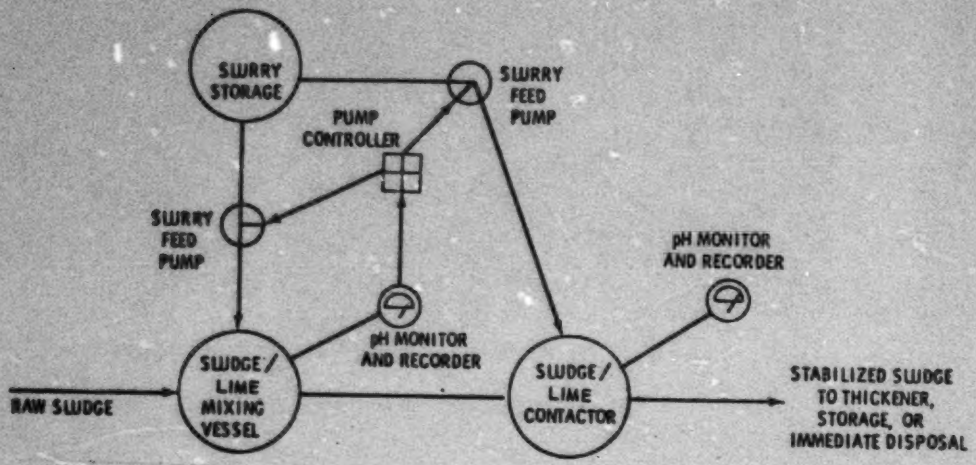

SLURRY STORAGE
SLURRY FEED PUMP
PUMP CONTROLLER
SLURRY FEED PUMP
pH MONITOR AND RECORDER
pH MONITOR AND RECORDER
SLUDGE/ LIME MIXING VESSEL
SLUDGE/ LIME CONTACTOR
RAW SLUDGE
STABILIZED SLUDGE TO THICKENER, STORAGE, OR IMMEDIATE DISPOSAL

Figure VI-1. Lime stabilization process flowsheet.

Mixing requirements for sludge slurries are also an important design consideration. The level of agitation should be high enough to keep solids suspended and spread the lime slurry evenly and rapidly throughout the mixing tank.

Typical mixer requirements are shown in Table VI-2 (see following pages).

Expected performance results are shown in Tables VI-3, VI-4, and VI-5 (see following pages) for chemical properties, bacterial composition and solids concentration of lime stabilized sludge.

sludge disposal

It may be difficult to find suitable disposal sites for lime treated sludge. This should be considered carefully for each site.

STAFFING REQUIREMENTS

Labor requirements for operation and maintenance including unloading of lime and operation and maintenance of the lime slaker, are shown in Table VI-6 (see following pages). The requirements are based on pounds per hour of continuous lime feed. These data were developed from "Costs of Chemical Clarification of Wastewater", EPA Contract No. 68-03-2186, final draft, December 1977.

TABLE VI-1. LIME REQUIRED FOR STABILIZATION TO pH 12 FOR 30 MINUTES

Sludge type	Sludge solids, %	Average lb $Ca(OH)_2$/ton dry solids	Range lb $Ca(OH)_2$/ton dry solids	Total volume treated	Average total solids mg/l	Average initial pH	Average final pH
Primary sludge[1]	3-6	240	120- 340	136,500	43,276	6.7	12.7
Waste activated sludge	1-1.5	600	420- 860	42,000	13,143	7.1	12.6
Septage	1-4.5	400	180-1,020	27,500	27,494	7.3	12.7
Anaerobic	6-7	380	280- 500	23,500	55,345	7.2	12.4

[1] Includes some portion of waste activated sludge.

Data in this Table developed from:

1. "Stabilization and Disinfection of Wastewater Treatment Plant Sludges", USEPA Technology Transfer, 1974.
2. "Lime Stabilized Sludge: Its Stability and Effect on Agricultural Land", EPA-670/2-75-012, April, 1975.

TABLE VI-2. TYPICAL MIXING REQUIREMENTS FOR SLUDGE SLURRIES

Tank size, gallons	Tank diameter, feet	Prime mover, hp Shaft speed, rpm	Mixer diameter, inches
5,000	9.6	7.5/125	32
		5/ 84	38
		3/ 56	43
15,000	13.9	20/100	45
		15/ 68	53
		10/ 45	63
		7.5/ 37	67
30,000	17.5	40/ 84	57
		30/ 68	61
		25/ 56	66
		20/ 37	81
75,000	23.75	100/100	62
		75/ 68	74
		60/ 56	79
		50/ 45	87
100,000	26.1	125/ 84	72
		100/ 68	78
		75/ 45	94

Data in this Table developed from "Stabilization and Disinfection of Wastewater Treatment Plant Sludges", USEPA Technology Transfer, 1974.

TABLE VI-3. CHEMICAL PROPERTIES OF RAW AND LIME STABILIZED SLUDGES

Sludge type	Alkalinity, mg/1	Total COD, mg/1	Soluble COD, mg/1	Total phosphate, mg/1	Soluble phosphate, mg/1	Total kjeldahl nitrogen, mg/1	Ammonia nitrogen, mg/1	Total solids, %
Raw primary	1,958	54,146	3,046	350	69	1,656	223	4.5
Lime stab. primary	4,313	41,180	3,556	283	36	1,374	145	4.9
Waste activated	1,265	12,810	1,043	218	85	711	38	1.3
Lime stab. waste activated	5,000	14,697	1,618	263	25	1,034	53	1.7
Septage	2,245	24,940	1,223	172	25	820	92	2.6
Lime stab. septage	4,305	17,487	1,537	134	2	597	84	2.7
Anaerobic digested	3,406	66,372	1,011	580	15	2,731	709	6.9
Lime stab. anaer. digest	11,400	58,692	1,809	381	3	1,980	494	5.8

References same as Table VI-1.

TABLE VI-4. COMPARISON OF BACTERIA IN ANAEROBIC DIGESTED VERSUS LIME STABILIZED SLUDGES

	Fecal coliform /100 ml	Fecal streptococci /100 ml	Total coliform /100 ml	Salmonella /100 ml	Ps. aeruginosa /100 ml
Anaerobically digested	$1,450 \times 10^3$	270×10^3	$27,800 \times 10^3$	6	42
Lime stabilized*					
Primary	4×10^3	23×10^3	27.6×10^3	3**	3
Waste activated	16×10^3	61×10^3	212×10^3	3	13
Septage	265	665	2,100	3	3

* To pH equal to or greater than 12.0

** Detection limit = 3

References same as Table VI-1.

TABLE VI-5. VOLATILE SOLIDS CONCENTRATION OF SLUDGES

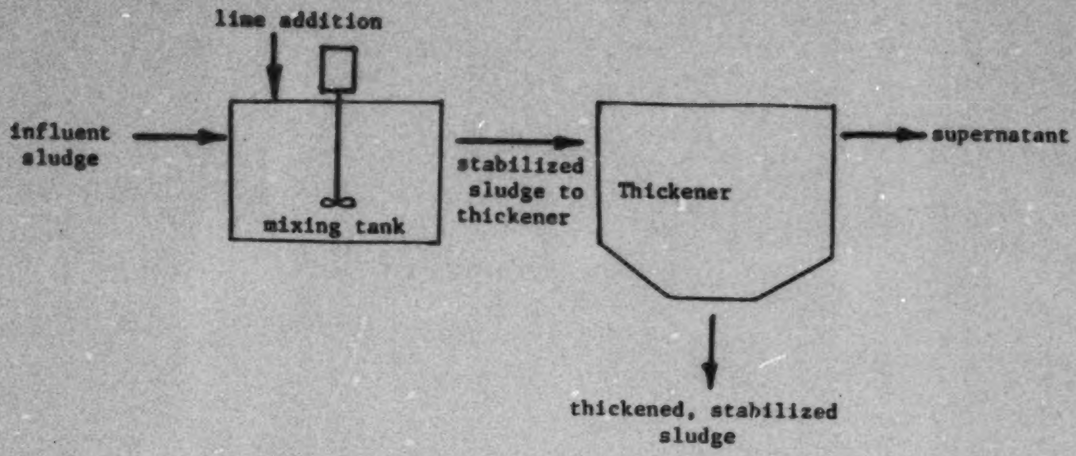
Sludge type	Sludge volatile solids solids concentration, mg/l	Lime stabilized sludge volatile solids concentration, mg/l
Primary	73.2	54.4
Waste activated	80.6	54.2
Septage	69.5	50.6
Anaerobically digested	49.6	37.5

References same as Table VI-2.

TABLE VI-6. LIME TREATMENT LABOR REQUIREMENTS

Lime feed, lb/hr	Operation and maintenance labor, hr/yr
10	966
100	1,183
1,000	1,975
10,000	6,570

MONITORING


lime addition
influent sludge
mixing tank
stabilized sludge to thickener
Thickener
supernatant
thickened, stabilized sludge

	Plant Size (mgd)	Sample Frequency	Sample Location	Sample Method	Reason for Test
Total Solids	All	1/day	Influent Sludge	Grab	Process Control
Suspended Solids	All	1/day	Influent and Stabilized Sludge	Grab	Process Control
pH	All	Continuous	Mixing Tank	Record Continuously	Process Control
Alkalinity	All	1/day	Influent Sludge	Grab	Process Control
Flow	All	Continuous	Influent Sludge	Record Continuously	Process Control

NORMAL OPERATING PROCEDURES

Startup

1. Open influent valve or gate and begin filling sludge mixer tank.
2. Start up lime feed.
3. Start mixers when sludge level is high enough.
4. Set up pH control monitor.
5. Set up the stabilized sludge thickener controls, if applicable, and place into operation.
6. Check operation of lime slaking mechanism.

Routine Operations

1. Inspect system twice per shift.
2. Carry out maintenance as required including clean up, washdown, and lime handling.
3. Take samples as outlined in MONITORING section.

Shutdown

1. Shutdown lime feed system.
2. Close sludge mixing tank influent valve or gate.
3. Drain the system if desired or shutdown sludge pumping.
4. Turn off mixing mechanism when level is below agitators.

CONTROL CONSIDERATIONS

Physical Control

types

Although lime is available in a number of forms, the most commonly used for sludge stabilization are quicklime and hydrated lime. Quicklime (unslaked limed) is almost entirely calcium oxide, (CaO). Quicklime does not react uniformly when applied directly to sludge, but first must be converted to the hydrated form, $Ca(OH)_2$. Hydrated or slaked lime is a powder obtained by adding sufficient water to quicklime to satisfy its affinity for water.

conveying Lime may be conveyed either mechanically by screw conveyors or bucket conveyors, or pneumatically.

feeding Lime is normally fed as a slurry because of its low solubility in water. Other advantages of applying lime as a slurry are that it is transported more readily as a slurry; better dispersion of the lime in the sludge is accomplished; preparation of the lime slurry with agitation reduces the tendency for lime to settle in the treatment vessels.

mixing Mixing is very important in the operation of a lime stabilization process. The sludge and lime must be well mixed to insure a uniform mixture. Excess lime is usually required to compensate for poor mixing.

Process Control

inspection The lime stabilization equipment should be checked several times per shift to assure proper operation of sludge mixing equipment, lime feeding equipment, pH control and pumps.

sampling Sampling should be performed as outlined under MONITORING. These samples may be obtained through valves provided in the system piping. If sampling points are not provided, it may be necessary to obtain samples directly from the tank contents.

analysis Samples should be analyzed according to procedures specified in Standard Methods.

pH The lime stabilization process is mainly controlled by the pH of the sludge-lime mixture. Lime should be added continuously until the desired pH level is reached and thereafter, as required to maintain the desired pH. This can be done monthly or by an automatic pH control. If the control is manual, the operator must monitor the pH several times a shift.

lime dose The lime needed to reach the desired pH level is affected by the type of sludge, its chemical makeup and percent solids. Therefore, the exact dosage can only be determined by actual experimentation at the plant.

mixing time Mixing time is usually a function of lime slurry feed rate and is not limited by the mixing capacity of the system. Therefore, mixing time is best reduced by increasing the capacity of the lime slurry tank.

EMERGENCY OPERATING PROCEDURES

Loss of Power

Short power interruptions should not greatly affect lime stabilization of sludge. Although electrical equipment will not operate, the stabilization process will not deteriorate if power is regained within about 30 minutes to an hour. If power is unavailable for a longer period of time the pH of the sludge-lime mixture may begin to fall. Septic conditions may develop if only a small amount of lime was added before the power failure occurred. The effect of potential septic conditions can be partially or totally overcome by aerating or mixing the contents of the system tanks and/or adding lime or chlorine.

Loss of Other Treatment Units

The loss of other treatment units should not greatly affect the operation of the lime stabilization process. If the loss of any process following lime stabilization creates a solids handling problem it may be necessary to haul sludge to another treatment facility or disposal area.

COMMON DESIGN SHORTCOMINGS

Shortcoming	Solution
1. Mechanical equipment fouled with rags and debris.	1. Remove rags and screened debris from wastewater stream prior to sludge treatment and dispose of separately. Do not run debris through a comminutor and return debris to the treatment process.
2. Inadequate process monitoring equipment.	2. Run frequent manual tests or install continuous pH monitoring equipment.
3. Lime solids settle out prior to feed point.	3. Provide mechanical mixers for dissolving solids and maintaining them in suspension prior to delivery to feed point.
4. Strong odors produced during sludge stabilization especially with diffused air mixing.	4. Provide adequate ventilation to dissipate odors created during mixing. These odorous gases may include ammonia which is stripped from the sludge.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Air slaking occurring during storage of quicklime.	1a. Adsorption of moisture from atmosphere when humidity is high.	1a. Moisture in storage facility from leaks or humid atmosphere.	1a. Make storage facilities airtight, and do not convey pneumatically.
2. Feed pump discharge line clogged.	2a. Chemical deposits.	2a. Visual inspection.	2a. Provide sufficient dilution water.
3. Grit conveyor or slaker inoperable.	3a. Foreign material in the conveyor.	3a. Broken shear pin.	3a. Replace shear pin and remove foreign material from grit conveyor.
4. Paddle drive on slaker is overloaded.	4a. Lime paste too thick.	4a. Visual inspection.	4a. Adjust compression on the spring between gear Reducer and water control valve to alter the consistency of the paste.
	4b. Grit or foreign matter interfering with paddle action.	4b. Visual inspection.	4b. Remove grit or foreign materials, try to obtain lime with a lower grit content, or install grit removal facilities in slaker or slurry line.
5. Lime deposits in lime slurry feeder.	5a. Velocity too low.		5a. Maintain continuously high velocity by use of a return line to the slurry holding tank.
6. "Downing" or incomplete slaking of quicklime.	6a. Too much water is being added.	6a. Hydrate particles coarse due to rapid formation of a coating.	6a. Reduce quantity of water added to quicklime (detention slakers-waters to lime ratio = 3¼:1 Paste slaker ratio = 2:1).

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
7. "Burning" during quicklime slaking.	7a. Insufficient water being added, resulting in excessive reaction temperature.	7a. Some particles left unhydrated after slaking.	7a. Add sufficient water for slaking (See Solution 7).
8. Sludge retains definite offensive odor after addition of lime.	8a. Lime dose too low.	8a. Check pH in sludge-lime mixing tank to assure desired level is reached.	8a. Increase lime dose, check pH monitor for possible malfunction.

MAINTENANCE CONSIDERATIONS

A good preventive maintenance program will reduce breakdowns which could be not only costly, but also very unpleasant for operating personnel. Plant components including the following should be inspected semiannually for wear, corrosion, and proper adjustment:

mechanical

1. Drives and gear reducers
2. Drive chains and sprockets
3. Shaft bearings and bores
4. Bearing brackets
5. Baffles and weirs
6. Electrical contacts in starters and relays
7. Suction lines and sumps

SAFETY CONSIDERATIONS

1. The equipment for lime stabilization of sludge presents no special hazards, however, general safety considerations should apply. At least two persons should be present when working in areas not protected by handrails. Walkways and work areas should be kept free of grease, oil, leaves and snow. Protective guards and covers must be in place unless mechanical/electrical equipment is locked out of operation. Wet lime sludge may increase the possibility or severity of electrical shock hazards.

2. Safety practices for handling lime are contained in "Safety Practice for Water Utilities", AWWA Manual M3.

REFERENCE MATERIAL

References

1. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, 1015 Eighteenth Street, N.W., Washington, D.C. 20036.

2. WPCF Manual of Practice No. 17 (WPCF No. 17) Paints and Protective Coatings for Wastewater Treatment Facilities.

3. Safety Practice for Water Utilities, No. M3. American Water Works Association, 2 Park Avenue, New York, N.Y. 10016.

Glossary of Terms and Sample Calculations

Lime dose is amount of lime required to satisfy the chemical demand present in the sludge and raise the pH to the desired level.

VII

CHLORINE TREATMENT

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PROCESS DESCRIPTION

process

Stabilization by chlorine addition has been developed and is marketed under the registered trade name "Purifax". The chemical conditioning of sludge with chlorine varies greatly from the more traditional methods of biological digestion or heat conditioning. First, the reaction is almost instantaneous. Second, there is very little volatile solids reduction in the sludge. There is some breakdown of organic material and formation of carbon dioxide and nitrogen; however, most of the conditioning is by the substitution or addition of chlorine to the organic compound to form new compounds that are biologically inert.

The chemical form in which chlorine is present in water is directly related to pH. The first reaction of chlorine is with ammonia (combined available chlorine), however, this is a small portion of the chlorine added for this process. Most of the chlorine (free available chlorine) ends up as either hydrochloric acid, HCl, or hypochlorous acid, HOCl. The HOCl subsequently breaks down into nascent oxygen, O, and HCl. Below pH 5, molecular chlorine, Cl_2, appears in solution and increases in concentration with decreasing pH. The equations for the reaction of free available chlorine in water can be summarized as follows:

$$Cl_2 + 2H_2O \longrightarrow HOCl + HCl + H_2O$$

$$HOCl \longrightarrow HCl + O \underbrace{+ Cl_2}_{\text{below pH5}}$$

$$+ Cl_2$$

Hypochlorous acid, HOCl, its subsequent by-product nascent oxygen, O, and molecular chlorine are all strong oxidants. The hydrochloric acid is not an oxidant or a disinfectant, but does lower the pH of the solution.

Generally, the entire process consists of a macerator, flow meter, recirculation pump, two reaction tanks, a chlorine eductor, chlorinator, evaporator, a pressure control pump, and 2 holding tanks. Variations are possible with the selection of the individual units depending on the nature of the sludge. Conventional grit removal equipment used for the plant influent will suffice for grit reduction of sludge processed through the oxidation unit. If grit removal equipment has not been provided for the plant then it should be added to this system. The type of macerator selected depends on the type of sludge being stabilized. The resulting maximum particle size should not exceed 1/4 inch. To provide optimum utilization of chlorine the system should be preceded by a sludge holding tank which includes some means of mixing or agitation. This is especially necessary for treating primary sludge. The primary sludge solids concentration is typically higher at the beginning of a pumping cycle and lower near the end of the cycle. Without provision of the holding tank the chlorine requirement would be variable and over- or under- chlorination a possibility. With the holding tank in use the chlorine requirement can be set at a constant rate. Use of thickeners ahead of the conditioning unit is optional. The sludge processing rate will be reduced for thicker sludges; specifically for primary or primary plus trickling filter greater than 4 percent, primary plus waste activated sludge greater than 2.6 percent, or waste activated sludge greater than 1 percent. The lower processing rates offset the reduction in volume obtained by thickening so there is no advantage in thickening to concentrations greater than those given above for the different types of sludge.

A schematic of the Purifax process is shown on Figure VII-1 (see following page). The sludge is first pumped through a macerator to reduce the particle size for optimum chlorine exposure. It is then mixed with conditioned sludge ahead of the recirculation pump at a ratio of 3.8 gallons of recirculated sludge for each gallon of raw sludge. The combined flow is then pumped through the first reaction tank where it is thoroughly mixed. A portion of the sludge then flows to the second reaction tank while the remainder is recirculated. Recirculation of a portion of the sludge aids in mixing and provides better utilization of the chlorine. The recirculation rate is normally held constant. A pressure control pump at the discharge end of the second reaction tank maintains a pressure of 30 to 40 psi on the entire system.

operation

Chlorine is added to the recirculated sludge line ahead of the recirculation pump. The passage of the conditioned sludge through the eductor creates a vacuum which causes chlorine gas to move from the chlorine supply into the sludge line. The recirculation of the conditioned sludge through the eductor satisfies the dilution requirements of the chlorine gas without introducing additional water into the system. The recirculation pump acts as a mixer for the raw and conditioned sludges. Almost all of the reaction between the sludge and chlorine takes place in the first reaction tank. This tank provides 3 minutes of detention time at design flow. The second reaction tank provides an additional 1.5 minutes of detention time. Operating the system under

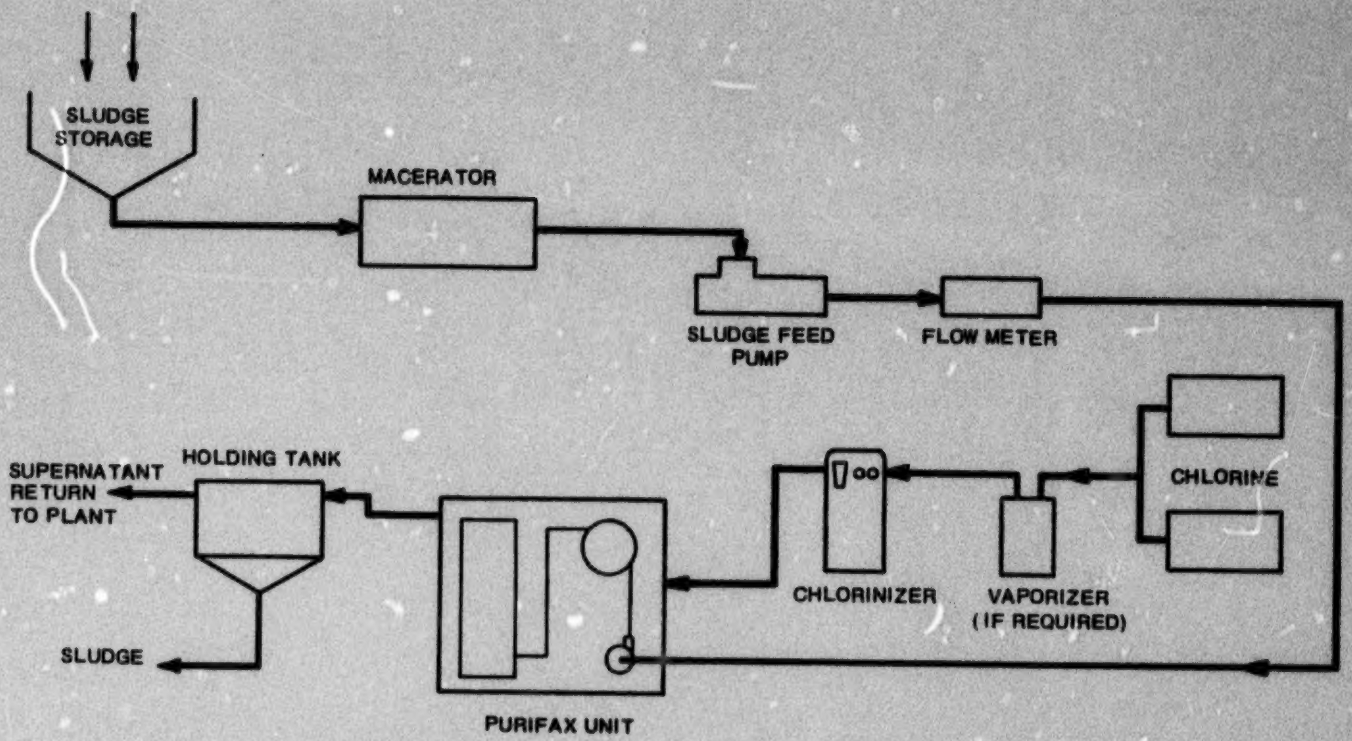

SLUDGE STORAGE
MACERATOR
SLUDGE FEED PUMP
FLOW METER
CHLORINE
VAPORIZER (IF REQUIRED)
CHLORINIZER
PURIFAX UNIT
HOLDING TANK
SUPERNATANT RETURN TO PLANT
SLUDGE

Figure VII-1. Schematic (courtesy of BIF)

pressure forces the chlorine to penetrate into the sludge particles to insure a complete reaction.

Chlorine is supplied to the unit from a separate chlorinator located in the same room as the chlorinators for disinfecting the plant effluent. Because of the large volumes of chlorine required for the Purifax unit, an evaporator is used ahead of the chlorinator.

supernatant return to process

The sidestreams that require further treatment result from the thickening and/or dewatering processes that follow the oxidation unit. The characteristics of the supernatant vary with the type of sludge being treated and the method of thickening or dewatering. The oxidized sludge should be contained in a holding tank or reservoir for at least 48 hours. This will allow time for the chlorine residual to approach zero and the pH to raise from 3.5 or 4.0 to 5.0 or 6.0. The BOD_5 and suspended solids concentrations obviously are quite variable but each should be less than 350 mg/l. The supernatant or filtrate sidestreams are routed to the plant headworks for treatment with the incoming sewage.

If the oxidized sludge is dewatered without provisions for the holding tank then sodium hydroxide or lime must be added to raise the pH. The quantities of filtrate or supernatant to be treated vary with the type of process(es) used. In general, the quantity of supernatant or filtrate to be treated is minor in terms of the total treatment plant capacity.

TYPICAL DESIGN CRITERIA & PERFORMANCE

The loading rates shown in Table VII-1 (see following page) apply to standard Purifax units.

TABLE VII-1. LOADING RATES

Type of sludge	Solids concentration, %	gpm/hp
Primary	≤ 4	2 -3.5
Primary & trickling filter	≤ 4	2 -3.5
Primary & waste act. sludge	≤ 2.6	2 -3.5
Primary & waste act. sludge	4.0	1.5-2.5
Primary & waste act. sludge	5.0	1.1-2.1
Waste activated sludge	1.0	2.9-5.1
Waste activated sludge	2.0	2.2-3.9
Waste activated sludge	3.0	1.5-2.6
Waste activated sludge	4.0	0.8-1.3
Anaerobic digester supernatant	0.2	2.9-5.1
Anaerobic digester supernatant	0.3	2.5-4.5
Anaerobic digester supernatant	0.4	2.1-3.8
Anaerobic digester supernatant	0.5	1.8-3.2
Septic tank sludge	2.0	2.9-5.1
Septic tank sludge	3.0	2.5-4.5
Septic tank sludge	4.0	2.2-3.9
Trickling filter humus	2.0	2.9-5.1
Trickling filter humus	3.0	2.5-4.6
Trickling filter humus	4.0	2.2-4.0

chlorine dosages

Chlorine dosages range from 600 to 4800 mg/l depending on the type of sludge and solids concentration. Generally, the units should be operated with the lowest concentration shown for each sludge type shown in Table VII-1. At these concentrations the chlorine dosage varies from 600 to 2000 mg/l or .005 to .017 pounds per gallon. The actual dosage used must be adjusted for each individual plant.

stabilized sludge characteristics

The stabilized sludge will have a pH of 2.5 to 4.5 and chlorine residual of 200 to 400 mg/l. The stabilized sludge will have chlorine smell and light brown color. Total solids, suspended solids, and volatile solids concentrations will be about the same as the raw sludge. When stored for 48 hours the chlorine residual will have fallen to 0 and the pH will have increased to 4.5 to 6.0. The organics will normally not decompose even after several days of storage.

Table VII-2 (see following page) shows the expected characteristics for sidestreams from typical thickening and dewatering operations as applied to the conditioned sludge.

TABLE VII-2. SIDESTREAM CHARACTERISTICS

Supernatant from Conditioned Sludge Holding	
BOD_5	50-150 mg/l
Suspended solids	50-200 mg/l
pH	4.5-6.0
Chlorine residual	0
Filtrate from Vacuum Filter	
BOD_5	100-350
Suspended solids	50-150
pH (with 20-30 lb/ton NaOH)	4.5-5.5
Chlorine residual	200-400 (unless stored)
Centrate from Solid Bowl Centrifuge	
BOD_5	200-400
Suspended solids	300-500
pH (with 20-30 lb/ton NaOH)	4.5-5.5
Chlorine residual	200-400 (unless stored)

STAFFING REQUIREMENTS

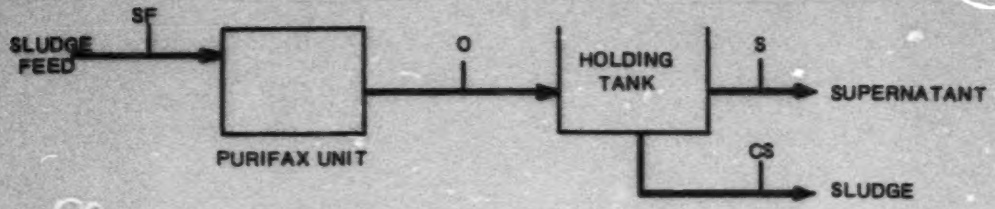
The staff requirements shown below apply to the Purifax process, macerator, pumps, and chlorination system. Dewatering or thickening operation and maintenance are not included.

Package Chlorine Treatment Unit Labor Requirements

Operation	2 hr/shift/unit
Maintenance	3 hr/shift/unit

The chemical oxidation process is automated. The main effort is visually checking the process and operating the ancillary equipment. Most of the systems now in operation are package type units.

MONITORING


SF
SLUDGE FEED
PURIFAX UNIT
O
HOLDING TANK
S
SUPERNATANT
CS
SLUDGE

SUGGESTED MINIMUM

	PLANT SIZE (MGD)	TEST FREQUENCY	LOCATION OF SAMPLE	METHOD OF SAMPLE	REASON FOR TEST
pH	ALL	1/D	SF, O, S, CS	G	P
	ALL	1/W	CE	G	P
SUSPENDED SOLIDS	ALL	1/D	SF, O, S, CS	G	P
VOLATILE SOLIDS	ALL	1/W	SF, O, S, CS	G	P
CHLORINE DEMAND	ALL	1/D	SF	G	P
CHLORINE RESIDUAL	ALL	1/D	O, S, CS	G	P
ORP	ALL	1/W	O	G	P

A. TEST FREQUENCY

D = DAY
W = WEEK

B. LOCATION OF SAMPLE

SF = SLUDGE FEED
O = OXIDIZED SLUDGE
S = SUPERNATANT
CS = CONDITIONED

C. METHOD OF SAMPLE

G = GRAB SAMPLE

D. REASON FOR TEST

P = PROCESS CONTROL

E. FOOTNOTES

Sensory Observations

The oxidized sludge should have a faint chlorine odor after processing, with no chlorine odor after 2 days storage.

The material should be light gray in color. If these characteristics change, the process control parameters should be checked. Each individual plant will result in processed sludge that has slightly varing sensory characteristics. After the plant has operated for several weeks then the sensory observations can be more critically reviewed. Major differences in chlorine odor may result with too little or too much chlorine. Darkening of the sludge color may result if the process is not properly operating. If either of the above occur, the chlorine residual and system pressure should be checked immediately. If these parameters are within acceptable ranges, then check for changes in the incoming sludge.

NORMAL OPERATING PROCEDURES

Pre-Startup

chlorine

Check operation of the chlorine pressure-reducing valve by turning ON the power switch on the sludge oxidation unit control panel. Turn the chlorine valve switch to the OPEN position, observe operation of valve actuator.

Turn switch to the CLOSED position.

time delays

Adjust time delay relays according to the manufacturer's instruction manual.

Startup

1. Adjust the chlorinator feed rate to a low setting.
2. Close the chlorine pressure-reducing valve bypass valve.
3. Turn on the chlorine supply to the chlorinator.
4. Turn the feed pump and macerator motor starter selector switches to AUTO.
5. Turn both selector switches in the PURIFAX motor starter panel to AUTO.
6. Turn the power switch and alarm switch ON and the chlorine valve switch to AUTO.

7. Depress the START pushbutton. When the motors start, adjust the speed of the pressure control pump to produce 30 psi at the process pressure gauge. If this is not done before the timing relay times out, the system will automatically shut down.

8. The vacuum gauge should read approximately 20 inches of mercury. The vacuum gauge on the chlorinator should read the same. The pump suction gauge should read approximately 5 psi. The pump discharge gauge should read approximately 30 psi.

9. Check the oxidation unit for obvious sludge leaks.

10. Belt adjustment - Adjust take-up on the recirculation pump belts until only a slight bow appears in the slack side.

11. Recheck the tension of new belts several times within the first 50 hours of operation and adjust if necessary.

12. Thereafter check the tension periodically.

13. Install belt guard.

14. When sludge is introduced into the system, it may be necessary to readjust the speed of the pressure control pump.

15. Adjust the chlorinator feed rate to the calculated rate.

16. Check for water at each pump seal by disconnecting the seal water tubing.

Routine Operations

The system operation is automatic after startup. Should a problem develop causing deviation from established operating limits, the system will automatically shutdown. The system cannot be restarted until the problem causing the shutdown has been corrected. The system should be checked twice a shift.

Shutdown

Normal shutdown is a sequential operation initiated by depressing the STOP pushbutton. The sequence of operation is as follows:

1. Depressing the STOP pushbutton causes immediate interruption of the circuit to the chlorine pressure-reducing valve causing it to close and shut off the chlorine gas supply.

2. The chlorine pressure switch senses the loss of chlorine gas pressure and its contacts open. After a sufficient time has elapsed to evacuate chlorine gas from the piping, an OFF delay relay, 3TR, is de-energized, closing the vacuum line valve.

3. When the vacuum valve closes, its auxiliary contacts open causing interruption of the circuits to the recirculation pump and pressure control pump motor starters. Auxiliary contacts in the starters open, interrupting the circuit to the seal flushing water solenoid valve and the remotely mounted control relay. The control relay is de-energized stopping the feed pump and macerator.

CONTROL CONSIDERATIONS

Physical Control

The control system is automatic, with little operator attention required.

Process Control

There are three variables that affect operation. They are throughput rate, chlorine feed rate, and system pressure.

throughput

The throughput rate has been designed for an expected solids concentration. The process chlorine feed is set based upon the expected rate of solids fed to the oxidation unit. If the actual solids concentration increases the throughput rate should be lowered.

chlorine feed

The chlorine feed rate is also adjusted based on throughput rate solids concentration, and/or monitoring results. If the chlorine residual increases or decreases beyond the limits of the recommended range, check the chlorine demand and reset the chlorine feed.

system pressure

If the above parameters are correct and the oxidized sludge characteristics are not within recommended limits, check the unit pressure. This should be between 30 and 40 psi.

EMERGENCY OPERATING PROCEDURES

Loss of Power

The oxidation unit will not operate without power. Raw sludge must be hauled to a landfill site or temporarily stored if facilities are available. If stored, the sludge must be processed when power is restored.

Loss of Other Treatment Units

Other treatment units that affect the oxidation unit include raw sludge thickening and oxidized sludge dewatering. If the raw sludge thickener is out of service the throughput rate will not be affected unless the maximum capacity is exceeded. If this occurs, the unit hours of operation will have to be extended. The chlorine feed rate should be adjusted. The amount of adjustment is determined by the results of a chlorine demand test.

If the oxidized sludge dewatering unit is out of service, then the disposal transport system and disposal site must be expanded to handle the increased volume.

Should an emergency occur requiring immediate shutdown and over-ride of normal sequential shutdown, an EMERGENCY STOP pushbutton is provided for this purpose. This device interrupts power to all components in the oxidation unit control circuit, shuts down all motors and closes the vacuum line valve and the chlorine pressure-reducing valve. The EMERGENCY STOP pushbutton is also used as a reset device to restore the system to normal operating status after an alarm situation has occurred.

The control system is designed to sense certain component and system failures. Pressure switches are located to sense over-pressure, excessive suction, low chlorine pressure and low eductor vacuum. A flow switch senses low flow. Motor starters sense motor overloading. Evaporator low temperature switch senses low water temperature.

Whenever deviation from established operating limits is sensed, lights indicating the cause of the problem will be activated, an audible alarm will call attention to the problem, and the system will be automatically shutdown until the problem is corrected. The audible alarm may be switched off. The indicating lamps remain lighted until the problem is corrected and the system reset.

A lock-out relay is included in the circuit that allows indicating alarm lamps to light, the audible alarm to sound, and prevents restarting without resetting the system when shutdown occurs in an alarm situation. It also prevents alarm devices from functioning during normal shutdown.

COMMON DESIGN SHORTCOMINGS

Shortcoming	Solution
1. Unit improperly sized.	1. Change operating time.
2. Inadequate holding tank capacity.	2a. Add another holding tank.
	2b. Use chemicals for pH adjustment and chlorine removal.
3. Inadequate storage for new sludge during power outage or shutdown.	3a. Store sludge in clarifiers (temporary).
	3b. Haul sludge to landfill.

3

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Oxidation unit shuts down (low chlorine supply pressure).	1a. No chlorine supply pressure.	1a. (1) Check chlorine tanks. (2) Check all manual valves in supply piping. (3) Check evaporator.	1a. (1) If empty, replenish supply. (2) Should be fully open. (3) See manufacturer's instructions.
	1b. Failure of electric chlorine pressure-reducing and shut-off valve to open.	1b. Check chlorine valve switch on control panel (should be in AUTO position).	1b. (1) Turn chlorine valve switch on control panel to OPEN position. If valve opens, and if chlorine pressure is indicated at chlorinator, the problem is in the control panel. (2) If valve remains closed, the problem is in the valve or valve operator.
	1c. Failure of chlorine pressure switch to close.	1c. (1) Check position of relay. (2) Check pressure setting and switch contacts.	1c. (1) Should be de-energized. (2) Adjust as needed.
	1d. Electrical failure in control panel.	1d. See wiring diagram.	1d. Correct where necessary.
2. Oxidation unit shut-down.	2a. Failure of feed pump motor to operate.	2a. (1) Check selector switch on motor starter. (2) Check motor overload heaters. (3) Check control relay.	2a. (1) Should be in AUTO position. (2) Correct if overloaded. (3) Should be energized, if not, problem is in control panel or control relay. If

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
2. Oxidation unit shut-down. (Cont'd)			2a. (3) relay is energized, relay has failed.
	2b. Failure of feed pump to pump.	2b. (1) Check lines for obstructions. (2) Check valves. (3) Pull pump.	2b. (1) Clean lines. (2) Open if necessary. (3) Repair per manufacturers instructions.
	2c. Failure of flow meter receiver contacts to close.	2c. (1) Check setting of auxiliary contacts. (2) Check valve in discharge piping.	2c. (1) Should be set for approximately 50% of the minimum system throughput rate. (2) Should be fully open.
	2d. Process pressure switch contacts opened.	2d. (1) Check valve in discharge piping. (2) Monitor pressure control pump speed.	2d. (1) Should be fully open. (2) Reduce speed.
	2e. Pump suction pressure switch contacts opened.	2e. Obstruction in inlet piping.	2e. Remove obstruction.
3. Oxidation unit shuts down (low vacuum).	3a. Break or leak in chlorine vacuum line piping.	3a. Locate leak.	3a. Repair.
	3b. Plugged eductor body.	3b. Disassemble and inspect.	3b. Remove two pipe plugs, vacuum gauge, switch assembly and vacuum line valve. Clean all openings.

TROUBLESHOOTING GUIDE

CHLORINE TREATMENT

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	3c. Recirculation pump fails to deliver required dynamic head of 30 psi. (discharge pressure minus suction pressure).	3c. (1) Check drive belt tension. (2) Check for worn impeller. (3) Check for air in piping.	3c. (1) Adjust. (2) Replace. (3) Bleed off air at vent plugs.
	3d. Failure of pressure control pump to maintain pressure in the system.	3d. (1) Check pump speed. (2) Check for worn impeller.	3d. (1) Increase speed. (2) Replace.
	3e. Failure of pressure control pump motor or recirculation pump motor to operate.	3e. (1) Check selector switches on the starter panel. (2) Check motor starter overloads.	3e. (1) Set on AUTO position. (2) Reset.
	3f. Failure of vacuum switch contacts to close.	3f. (1) Check switch assembly and vacuum gauge. (2) Check vacuum setting and switch contact. (3) Check for loss of oil.	3f. (1) Replace. (2) Clean and reset. (3) Fix leak and/or refill.
	3g. Electrical failure in control panel.	3g. Check wiring diagram.	3g. Repair.
4. Macerator stopped.	4. Jammed with debris.	4. Inspect.	4. Turn off power, remove obstruction.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
5. Indication of vacuum at oxidation unit but none at chlorinator.	5a. Diaphragm check valve plugs.	5a. Inspect.	5a. Disassemble and clean.
	5b. Failure of vacuum line valve ball to open.	5b. Inspect.	5b. (1) Replace with spare valve. (2) Disassemble and replace broken ball or shaft.
6. Depressing STOP button on control panel, unit continues to run longer than normal shutdown time.	6a. Failure of electric chlorine pressure-reducing and shut-off valve to close.	6a. Check chlorine pressure at chlorinator.	6a. (1) If there is pressure, turn chlorine valve switch on control panel to the closed position. (2) If there is still pressure, the valve is stuck open - replace. (3) If there is no pressure, the problem is in the control panel (correct wiring or fuse).
	6b. Failure of chlorine pressure switch contacts to open.	6b. Check position of relay.	6b. If energized, the pressure switch is stuck open.
	6c. Failure of vacuum line valve limit switch contacts to open.	6c. (1) Inspect. (2) Check valve operator.	6c. (1) Replace with spare valve. (2) If in the OPEN position, problem is in motor, gearing, limit switches, or cams. (3) If closed, problem is in the limit switch or cam.

MAINTENANCE CONSIDERATIONS

Inspect motors at regular intervals; keep motors clean and ventilation openings clear.

diaphragm check valve

Check valve may become clogged causing sludge to back-up into chlorinator. Periodically disassemble and clean. Replace diaphragm and spring if they are deteriorated.

vacuum line valve

Valve ball and seats may become scored causing sludge to back-up into diaphragm check valve. Periodically disassemble by unscrewing union nuts, with valve in CLOSED position, remove carrier and ball by pressing on flat spot on ball. Replace ball and seats if scored.

When reassembling valve, use caution. Only hand tighten union nuts.

macerator

Check the macerator twice daily for debris.

SAFETY CONSIDERATIONS

The major concerns are contact with the low pH and the high chlorine concentration of the oxidized sludge. Human contact with the oxidized sludge should be avoided. If this occurs, shower immediately.

The macerator can be dangerous if maintenance is attempted while the unit is turned on. Be sure the power is off before doing maintenance work.

Safety practices for handling chlorine are contained in "Safety Practice for Water Utilities", AWWA Manual M3.

Generation of chlorinated hydrocarbons may be a problem, but the magnitude of any such problem cannot be determined at this time.

REFERENCE MATERIAL

References

1. Safety Practice for Water Utilities, No. M3. American Waterworks Association, 2 Park Avenue, New York, N.Y. 10016.

2. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, 1015 Eighteenth St., N.W., Washington, D.C. 20036

Glossary of Terms and Sample Calculations

1. **Chlorine dosage** is the amount of chlorine required oxidize the sludge (chlorine demand) plus the desi residual. The dosage is computed as mg/l concentr and the chlorine feed system set at the equivalent lb/day feed rate.

   Given a desired chlorine residual of 300 mg/l and chlorine demand of 800 mg/l, the chlorine dosage a resulting feed rate (for 12,000 gal/day throughput) are computed as follows.

   Chlorine dosage = Chlorine demand + desired residu

   = 300 mg/l + 800 mg/l

   = 1100 mg/l

   Feed rate, lb/day = 1100 mg/l x 8.34 x .012 mgd

   = 110 lb/day

2. **Throughput rate** is the gallons of sludge fed to the unit per unit time (gpm or gpd).

3. **Oxidized sludge** is the chemical oxidation unit effl

4. **Conditioned sludge** is the oxidized sludge that has been conditioned by a holding tank or chemical trea to raise the pH and reduce the chlorine residual.

5. **Nascent oxygen** is uncombined oxygen in molecular fo (O).

6. **Oxidant** is an agent which oxidizes a substance by r ing one or more electrons from an atom, ion, or molecule.

VIII

CENTRIFUGATION

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PROCESS DESCRIPTION

The centrifuge is essentially a sedimentation device in which the solids-liquid separation is enhanced by rotating the liquid at high speeds so as to subject the sludge to increased gravitation forces.

applications

Centrifuges have been used for both sludge thickening and dewatering especially for waste activated sludge and digested sludges. The disc type and the solid bowl centrifuges are well suited to thickening operations. Centrifuges can be used to classify sludges according to relative specific gravity. For instance, phosphorus rich sludge can be removed from lime sludge to enable efficient recovery and reuse of the lime.

Three types of centrifuges have been used for sludge dewatering.

1. Solid bowl centrifuge - This is the most widely used type for dewatering of sewage sludge. This centrifuge assembly (Figure VIII-1, see following page) consists of a rotating bowl and conveyor. The rotating bowl, or shell, is supported between two sets of bearings and includes a conical section at one end to form a dewatering beach or drainage deck. Sludge enters the rotating bowl through a stationary feed pipe extending into the hallow shaft of the rotating screw conveyor and is distributed through ports into a pool within the rotating bowl.

   The helical rotating conveyor moves the sludge solids across the bowl, up the beaching incline to outlet ports and then to a sludge cake discharge hopper.

   As the liquid sludge flows through the bowl toward the overflow devices, progressively finer solids are settled centrifugally to the rotating bowl wall. The water or centrate drains from the solids and back into the pool. Centrate is discharged from the bowl through ports in the end which maintain the pool in the bowl at the desired depth.

   Most solid bowl machines employ the countercurrent flow of liquid and solids described above and illustrated in Figure VIII-1. They are appropriately referred to as

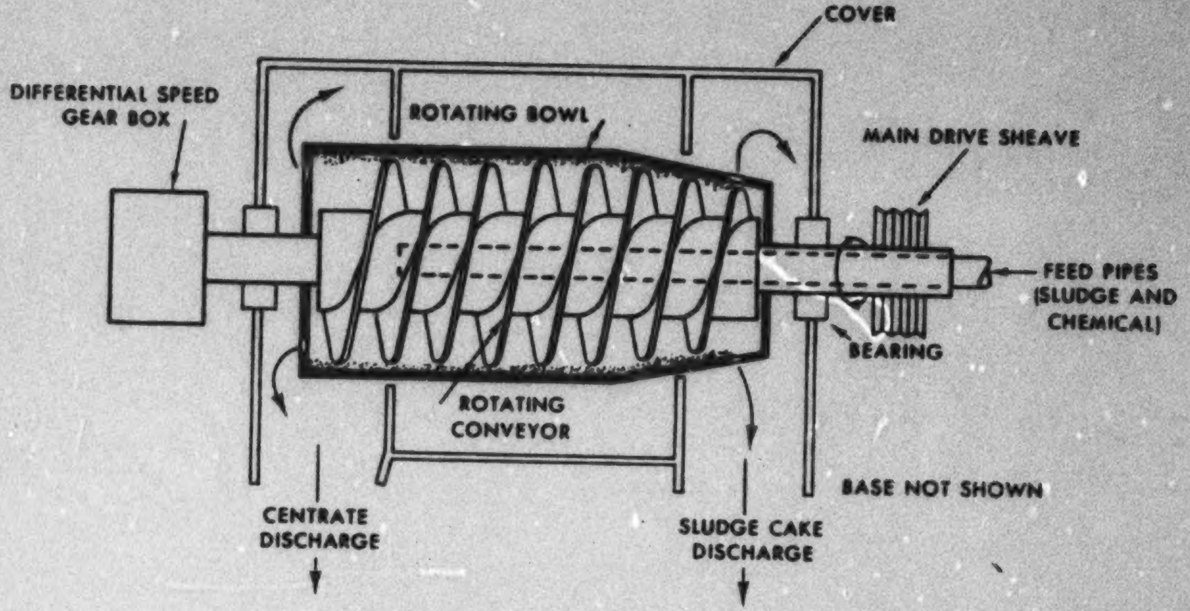

COVER
DIFFERENTIAL SPEED GEAR BOX
ROTATING BOWL
MAIN DRIVE SHEAVE
FEED PIPES (SLUDGE AND CHEMICAL)
BEARING
ROTATING CONVEYOR
BASE NOT SHOWN
CENTRATE DISCHARGE
SLUDGE CAKE DISCHARGE

Figure VIII-1. Continuous countercurrent solid bowl conveyor discharge centrifuge.

"countercurrent" centrifuges. Recently a "cocurrent" centrifuge design was introduced in which the solids and liquid flow in the same direction. General construction is similar to the countercurrent design except there are no centrate ports in the bowl head. Instead, the centrate is withdrawn by a skimming device near the junction of the bowl and the beach.

2. Basket centrifuge - This centrifuge is also referred to as the imperforate bowl, knife discharge type and is a batch dewatering unit that rotates around the vertical axis. The sludge is charged into the basket and forms an annular ring as the unit rotates. The liquid (centrate) is displaced over a baffle or weir at the top of the unit. When the solids concentration reaches the desired limit the centrifuge is stopped. A knife or skimmer displaces the cake from the vertical wall and out the bottom openings. A schematic is shown in Figure VIII-2.

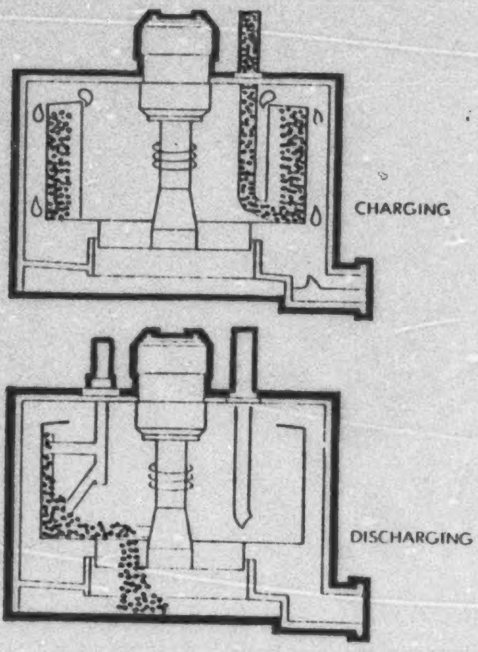


Figure VIII-2. Basket centrifuge in charge and discharge cycle.

3. **Disc centrifuge** - The disc centrifuge is continuous flow variation of the basket centrifuge as shown in Figure VIII-3. This centrifuge is prone to plugging and in some cases as the sludge may have to be screened prior to centrifugation.

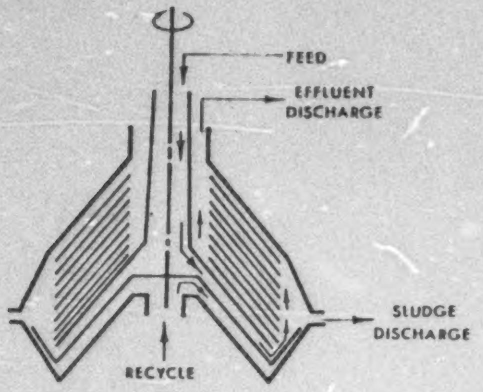


Figure VIII-3. Disc-type centrifuge.

sidestream

The centrate is usually returned to the plant influent or some other appropriate point in the main treatment process. Return of centrate to flotation thickeners has proven satisfactory.

TYPICAL DESIGN CRITERIA & PERFORMANCE

loading rates

A number of variables, including sludge feed rate, solids characteristics, temperature, and conditioning processes influence the sizing of centrifugation equipment for a particular application. Of these, sludge feed rate is the parameter most commonly used for sizing centrifuges. Single centrifuge capacities range from 4 gpm to about 250 gpm. Typical feed rates for several sizes of solid bowl centrifuges are shown in Table VIII-1 for typical municipal waste sludge.

TABLE VIII-1. SOLID BOWL CENTRIFUGE TYPICAL FEED RATES

Machine size, in	Feed rate lb dry solids/hr
18	300 to 800
24	700 to 2,000
36	1,500 to 3,500

Expected centrifuge performance is shown in Table VIII-2 (see following page) for a number of conditions. These data were developed from "Process Design Manual for Sludge Treatment and Disposal", EPA 625/1-74-006 and actual plant data.

TABLE VIII-2. EXPECTED CENTRIFUGE PERFORMANCE

Solid Bowl, Dewatering Performance

Wastewater sludge type	Sludge Cake Characteristics Solids,%	 Solids recovery,%	 Polymer addition
Raw or digested primary	25-35	90-95	2-4 lbs/ton
	28-35	70-90	no
Raw or digested primary, plus trickling filter humus	20-30	80-95	5-15 lbs/ton
	25-35	60-75	no
Raw or digested primary, plus activated sludge	15-30	80-95	5-20 lbs/ton
	15-25	50-65	no
Activated sludge	8-9	80-85	5-10 lbs/ton
Oxygen activated sludge	8-10	80-85	3-5 lbs/ton
High-lime sludges	50-55	90	no
Lime classification	40	75	no
Heat treated sludge	30-50	85-90	no
Heat treated sludge	30-50	92-99	2-5 lbs/ton

Typical Thickening Performance
(Based on limited plant operating experience)

Type of sludge	Centrifuge type	Underflow solids, %	Feed solids, %	Solids recovery, %	Polymer requirement, lb/ton
WAS	Disc	4-5.5	0.75-1.0	80-90	None
EAS (after roughing filter)	Disc	5-7	0.7	80-97	None
EAS	Basket	9-10	0.7	90-70	None
EAS	Solid-bowl	5-13	0.4-1.5	70-90	None
				85	<5
				90	5-10
				95	10-15

WAS = waste activated sludge
EAS = extended aeration waste sludge

polymers

The use of polymers has increased the range of materials that can be dewatered satisfactorily by centrifuges. The degree of solids recovery can be regulated over rather wide ranges depending on the amount of polymer used. A wetter sludge cake is usually produced when polymers are used because of the increased capture of fines.

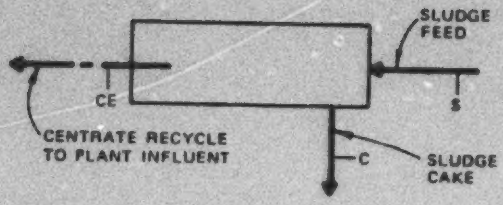
STAFFING REQUIREMENTS

Labor requirements for operation and maintenance of centrifuges are shown in Table VIII-3. The requirements are based on the annual solids feed rate. Centrifuge maintenance requires highly trained personnel and varies considerably depending on whether major maintenance is performed on site or if machines are rebuilt by service shops.

TABLE VIII-3. CENTRIFUGE LABOR REQUIREMENTS

Annual dry solids applied, dry tons/yr	Labor, hr/yr Operation	Maintenance	Total
100	700	200	900
500	1,000	300	1,300
1,000	1,500	400	1,900
5,000	4,000	1,000	5,000
10,000	7,000	1,800	8,800
50,000	30,000	8,000	38,000

MONITORING


SLUDGE FEED
CE
S
CENTRATE RECYCLE TO PLANT INFLUENT
C
SLUDGE CAKE

NOTE:
SOLID BOWL TYPE SHOWN. FLOW PATTERN IS SIMILAR FOR OTHER MODELS.

SUGGESTED MINIMUM

	PLANT SIZE (MGD)	TEST FREQUENCY	LOCATION OF SAMPLE	METHOD OF SAMPLE	REASON FOR TEST
TOTAL SOLIDS	ALL	1/D	S C	G	P
BOD	ALL	1/W	CE	G	$P^{(2)}$
SUSPENDED SOLIDS	ALL	1/D	CE	G	P
SETTLEABLE SOLIDS	ALL	1/H	CE	G	P
FLOW	ALL	R	CE	R	$P^{(1)}$

A. TEST FREQUENCY

H = HOUR
D = DAY
W = WEEK
R = RECORD CONTINUOUSLY

B. LOCATION OF SAMPLE

S = SLUDGE FEED
C = CAKE
CE = CENTRATE

C. METHOD OF SAMPLE

G = GRAB SAMPLE
R = RECORD CONTINUOUSLY

D. REASON FOR TEST

P = PROCESS CONTROL

E. FOOTNOTES:

1. DAILY OPERATION ASSUMED.
2. FOR CONTROL OF PROCESS RECEIVING THIS FLOW.

NORMAL OPERATING PROCEDURES

Startup

The manufacturer's handbooks should be consulted for specific instructions covering all equipment variations, however, the following general considerations should apply to most units. Centrifuge construction and features vary widely.

1. Confirm operation of sludge pumps, dewatered sludge conveyor and centrate return pumps.
2. For oil lubricated centrifuges:
   a. Check oil level. Open supply valve for oil-cooling water, if applicable.
   b. Start the oil pump, check oil temperature, and adjust cooling water to desired flow, if applicable.
3. For grease lubricated bearings make sure they are properly greased.
4. Start the centrifuge drive motor. If any severe or unusual vibration occurs shut the system down immediately, however, never stop the lubricating system before the centrifuge stops.
5. Open the sludge feed valve and check the ammeter occasionally to make certain the centrifuge is not being overloaded.

Routine Operations

Once in operation the centrifuge should run with very little attention. A list of suggested routine operational procedures follows and should be checked regularly as applicable to the particular machine.

1. Check level in oil reservoir.
2. Check flow of oil to bearings.
3. Check flow of cooling water and oil temperature to assure it is operating in the proper range.
4. Check machine vibration. When vibration becomes noticeable, machine should be overhauled. Continued

operation when vibration is excessive may damage bearings and other machine parts.

5. Check ammeter reading to assure that centrifuge loading is normal. An above average reading indicates overloading.

6. Check bearings for unusual noises.

7. Check bearing temperatures by hand feel. Grease lubricated bearings which run hot are probably overly lubricated.

8. Check system for leaks.

In the event a torque overload occurs the system should automatically shutdown. After the machine stops turn the torque arm to determine if the machine is blocked by solids. If the machine turns without obstruction reset the control and allow a sufficient cooling period before restarting. If the machine can not be cleared so it rotates freely, the centrifuge may require disassembly. In this case consult manufacturer's instructions.

Shutdown

1. Stop feed to centrifuge and thoroughly flush with hot water or solvent. This is extremely important.

2. Turn the centrifuge off.

3. Continue flushing until the centrifuge stops.

4. Turn off the lubricating system including the cooling water, but not until the centrifuge comes to a complete stop.

5. If the flushing procedure does not remove all of the deposits, the machine may have to be disassembled for cleaning. In this case consult the manufacturer's instructions.

6. The machine should not be restarted unless it has been properly flushed and it can be turned by hand.

CONTROL CONSIDERATIONS

Physical Control

For proper operation and safety, centrifuge systems require a certain amount of instrumentation such as motor shutdown, torque monitor, vibration monitor, running lights, control switch, oil pressure indicator and low pressure alarm, oil temperature indicator and ammeter.

Process Control

There are several variables that can be controlled by the operator to affect optimum centrifuge performance.

sludge feed

In general, the sludge variables that improve gravity sedimentation also improve centrifugation. If the sludge feed is increased, in continuous flow systems, the resident period decreases and the solids recovery will decrease. Also, within limits, if the slurry temperature is increased, the solids recovery and the cake solids will improve. This is rarely practiced since it is costly and generally not a good economic alternative.

chemicals

The use of chemicals, usually polymers, may improve solids recovery, but a wetter cake is generally produced because additional fines are captured.

For the solid bowl centrifuge, changes in the bowl speed, pool depth, or conveyor speed will affect performance. This is shown in Table VIII-4.

TABLE VIII-4. INFLUENCE OF MACHINE VARIABLES ON OPERATION OF SOLID BOWL CENTRIFUGE

Process change	Cake moisture	Solids recovery
Increase bowl speed	Decrease	Increase
Increase pool depth	Increase	Increase
Increase conveyor speed	Increase	Decrease
Polymer feed	Increase	Increase

pool depth

The bowl is normally equipped with adjustable dams or weirs for changing pool depth. Consult manufacturer's instructions for changing the pool depth as this generally requires partial disassembly.

The optimum settings for these variables depend on the quality of the cake and centrate desired and on the feed solids characteristics. Therefore, as with vacuum filters, it is best to try various settings and establish a centrifuge performance curve.

EMERGENCY OPERATING PROCEDURES

Loss of Power

During a power outage the centrifuge should be cleaned as well as possible in accordance with normal shutdown procedures and all switches and valves shut off. This will enable normal startup procedures to be followed when power is restored. If the centrifuge shuts down because of tripped relays, blown fuses, or the action of other safety devices the cause must be determined and proper adjustments made before restarting the equipment.

Loss of Other Treatment Units

The loss of treatment units that precede the centrifuge may affect centrifuge performance and require control adjustments. For example, the loss of the sludge thickener will result in a wetter sludge feed to the centrifuge. A loss of a process following the centrifuge should not have any affect on operation unless an alternative method of sludge disposal requires control adjustments to produce a cake with a different solids concentration.

COMMON DESIGN SHORTCOMINGS

Shortcoming	Solution
1. Excessive corrosion of parts; particularly the rotating conveyor.	1. Replace components affected with more suitable materials.
2. Flushing supply not strained and plugs nozzles.	2. Install strainer.
3. No means for removal of bowl assembly.	3. Install overhead hoist or use portable lifting frame.
4. Rigid piping connections to centrifuge and excessive vibration of piping.	4. Install flexible connections.
5. Lack of adequate degritting causes excessive wear.	5. Install degritting system.

TROUBLESHOOTING GUIDE

CENTRIFUGATION

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Centrate clarity inadequate.	1a. Feed rate too high.	1a. Flow records.	1a. Reduce flow.
	1b. Low pool depth.	1b. Setting of weirs.	1b. Increase pool depth to improve clarity.
	1c. Conveyor screws worn.	1c. Vibration; excessive solids buildup in machine.	1c. Repair or replace conveyor.
	1d. Speed too high.	1d. Pulley setting.	1d. Change pulley setting for lower speed.
	1e. Feed solids too high.	1e. Spin test on feed sludge - should be <40% by volume.	1e. Dilute the feed sludge.
	1f. Chemical conditioning improper.	1f. Chemical feed rate.	1f. Change chemical dosage.
2. Cake too wet.	2a. Feed rate too high.	2a. Flow records.	2a. Reduce flow.
	2b. High pool depth.	2b. Setting of weirs.	2b. Decrease pool depth to improve dryness.
	2c. Speed too low.	2c. Pulley setting.	2c. Change pulley setting for higher speed.
	2d. Excessive chemical feed.	2d. Chemical feed rate.	2d. Decrease chemical dosage.
3. Centrifuge torque control trips.	3a. Feed rate too high.	3a. Flow records.	3a. Reduce flow.
	3b. Feed solids too high.	3b. Spin test on feed sludge - should be <40% by volume.	3b. Dilute feed sludge.
	3c. Foreign material in machine.	3c. Inspect interior.	3c. Remove conveyor and remove foreign material.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	3d. Gear unit is misaligned.	3d. Vibration.	3d. Correct the alignment.
	3e. Faulty bearing, gear, or spline.	3e. Inspect.	3e. Replace faulty parts.
4. Excessive vibration.	4a. Improper lubrication.	4a. Check lubrication system.	4a. Provide correct lubrication.
	4b. Improper adjustment of vibration.	4b. Vibration isolators.	4b. Adjust isolators.
	4c. Discharge funnels may be contacting centrifuge.	4c. Position of funnels.	4c. Reposition slip joints at funnels.
	4d. Portion of conveyor screw may be plugged with solids causing unbalance.	4d. Interior of machine.	4d. Flush out centrifuge.
	4e. Gear box improperly aligned.	4e. Gear box alignment.	4e. Align gear box.
	4f. Pillow block bearing damage.	4f. Inspect bearings.	4f. Replace bearings.
	4g. Rotating parts out of balance.		4g. Balance rotating parts.
	4h. Parts not tightly assembled.		4h. Tighten parts.
	4i. Uneven wear of conveyor.	4i. Inspect conveyor.	4i. Resurface, rebalance.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
5. Sudden increase in power consumption.	5a. Contact between bowl and accumulated solids in centrifuge case.	5a. Solids plows; look for polished area on outer bowl.	5a. Apply hard surfacing to areas with water.
	5b. Effluent pipe plugged.	5b. Check for free discharge of solids.	5b. Clear effluent pipe.
6. Gradual increase in power consumption.	6a. Conveyor screw wear.	6a. Conveyor condition.	6a. Resurface screw.
7. Spasmodic, surging solids discharge.	7a. Pool depth too low.	7a. Weir position.	7a. Increase pool depth.
	7b. Conveyor screw rough.	7b. Improper hard surfacing or corrosion.	7b. Rebuild conveyor screw.
	7c. Feed pipe (if adjustable) too near bowl beach.		7c. Move feed pipe to effluent end.
	7d. Machine vibration excessive (See item 4).		
8. Centrifuge shuts down (or will not start).	8a. Tripped circuit breaker or fuses.	8a. Electrical.	8a. Correct problem and restart.
	8b. Overload relay tripped.	8b. Overload relay.	8b. Flush machine, reset overload relay.
	8c. Torque control tripped.	8c. (See item 3)	
	8d. Vibration switch tripped.	8d. (See item 4)	

MAINTENANCE CONSIDERATION

For routine equipment maintenance considerations such as oiling or greasing frequency or filter replacement consult manufacturer's instructions.

A hoist in good working order should be available for disassembly of the centrifuge.

A major consideration is whether or not the machine overhaul is done locally or by returning the machine (or parts) to a qualified repair shop. If qualified personnel are available, the machine can be overhauled locally with specialized work such as balancing performed by qualified local shops. Otherwise, the machine or the worn parts should be repaired by a qualified repair station or at the manufacturer's shop.

Plant personnel should have spare parts and tools for the following maintenance items if they are to do the work:

mechanical

1. Replace shear pins
2. Replace main bearings
3. Replace seals
4. Replace conveyor bushings
5. Replace thrust bearing seal
6. Replace or repair feed and discharge ports

SAFETY CONSIDERATIONS

1. Make sure that protective guards which may have been removed to service belts, gears, and other exposed moving parts have been replaced.

2. Don't wear loose clothing when servicing or operating the centrifuge.

3. Observe all electrical safety criteria.

4. Do not operate the machine under conditions that may produce excessive vibration (bowl not properly flushed), or if the vibration shutdown is inoperative.

REFERENCE MATERIAL

References

1. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, 1015 Eighteenth Street, N.W., Washington, D.C. 20036.

2. Process Design Manual for Sludge Treatment and Disposal, EPA 625/1-74-006. U.S. Environmental Protection Agency, Technology Transfer, Cincinnati, Ohio 45268.

3. WPCF Manual of Practice No. 11, Chapter 9, Operation of Wastewater Treatment Plants, Sludge Dewatering.

4. Process Design Manual for Sludge Treatment and Disposal, Chapter 4, EPA 625/1-74-006. U.S. EPA Technology Transfer, Cincinnati, Ohio 45268.

5. Estimating Laboratory Needs for Municipal Wastewater Treatment Facilities, EPA 430/9-74-002, June, 1973, U.S. Environmental Protection Agency, Office of Water Program Operations, Washington, D.C. 20460.

Glossary of Terms and Sample Calculations

1. Solids recovery is the ratio of cake solids to feed solids for equal sampling times. It can be calculated with suspended solids and flow data or with only suspended solids data. The centrate solids must be corrected if chemicals are fed to the centrifuge.

Recovery =

$$\frac{\left(\text{wet cake flow, } \frac{\text{lb}}{\text{hr}}\right)(\text{cake solids, \%})\ (100)}{\left(\text{wet feed flow, } \frac{\text{lb}}{\text{hr}}\right)\ (\text{feed solids, \%})}$$

Recovery =

$$\frac{(\text{cake solids, \%})(\text{feed solids, \% - centrate solids, \%})(100)}{(\text{feed solids, \%})(\text{cake solids, \% - centrate solids, \%})}$$

2. Centrate solids must be corrected if chemicals are added to centrifuge as follows. The centrate solids must be corrected because the centrate is diluted by the extra water from the chemical and chemical dilution water feeds. The measured centrate solids, therefore, are less than the actual solids would be without the added water from the chemical feed.

correction factor =

$$\frac{(\text{feed rate,gpm})+(\text{chemical flow,gpm})+(\text{dilution water,gpm})}{\text{feed rate, gpm}}$$

corrected centrate solids =

(measured centrate solids) (correction factor)

3. Solids feed rate is the dry solids feed to the centrifuge.

$$(\text{feed flow, gpm})\left(\frac{8.33\text{ lb}}{\text{gal}}\right)\left(\frac{\text{feed solids, \%}}{100}\right)\left(\frac{60\text{ min}}{\text{hr}}\right)$$

4. Cake solids discharge rate is the dry solids cake discharge from the centrifuge.

dry cake solids discharge rate =

(dry solids feed rate) (solids recovery)

IX

VACUUM FILTRATION

CONTENTS

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PROCESS DESCRIPTION

process

A vacuum filter basically consists of a cylindrical drum which rotates partially submerged in a vat of sludge. The filter drum is divided into compartments by partitions or seal strips. A vacuum is applied between the drum deck and filter medium causing filtrate to be extracted and filter cake to be retained on the medium during the pickup and cake drying cycle. The filter medium may be a cloth made of natural or synthetic fibers, stainless steel wire mesh or coil springs. In the drum filter shown in Figure IX-1 (see following page), the cake of dewatered sludge is removed by a fixed scraper blade, however there are alternative designs which use other methods for sludge removal.

The following major equipment variations are common:

equipment variations

1. Scraper - discharge mechanism: The filter drum operates continuously with a vacuum pickup forming and filtering zone, a vacuum cake drying zone, and a pressure blow back or discharge zone. A positive air pressure is maintained in the segment just ahead of the sludge scraper blade to aid in removal of the dried cake. A fine spray may be used to clean the filter medium with a catching trough beneath to dispose of the washings.
2. String discharge filters: Closely spaced strings around the filter drum, the medium, and a set of discharge and return rolls carry the sludge cake and then free it from the medium and discharge it to a hopper. The strings pass through a set of aligning combs before returning to the drum.
3. Belt-medium filters: A traveling woven cloth or metal belt serves as the filter medium and transports the sludge cake to the discharge roll in a manner similar to that of the string discharge filters. The belt can be washed on both sides, if desired, before positioning back on the drum.
4. Coil-medium filters: Two layers of stainless steel springs wrapped around the drum act as the filter medium. When the two layers of springs leave the drum they separate in such a manner that the sludge cake is lifted off the lower layer of coil springs and discharged off

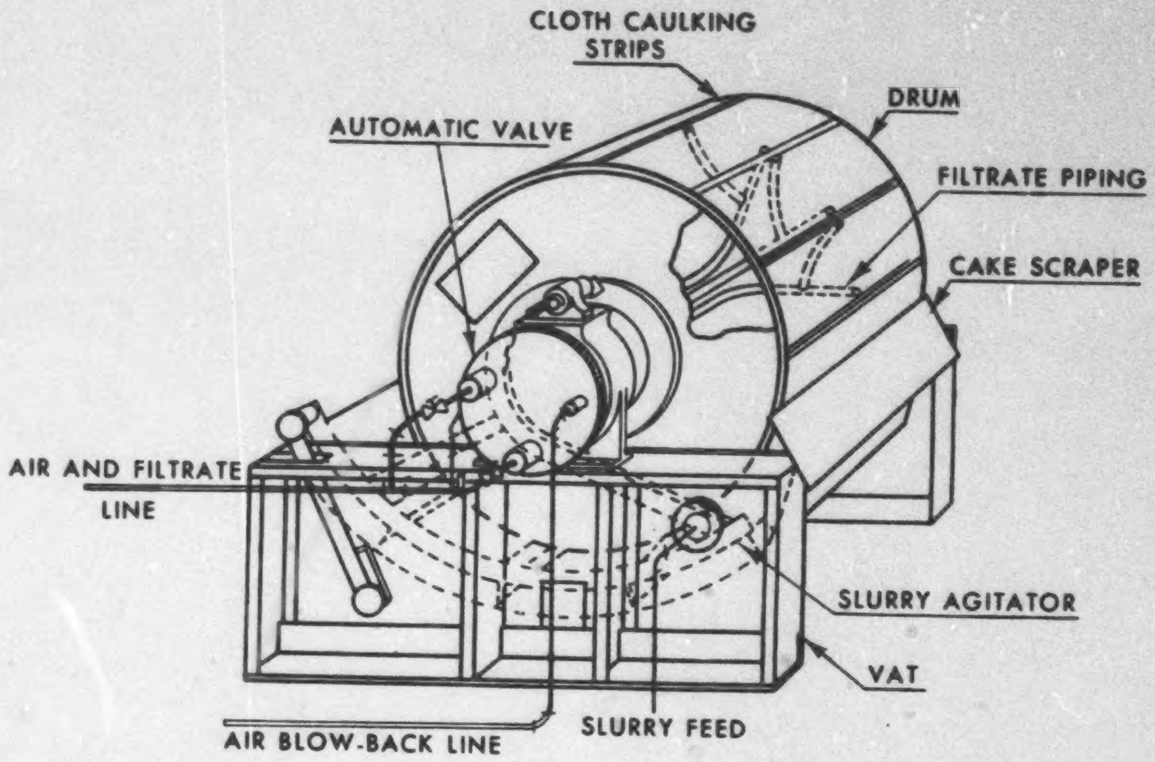

CLOTH CAULKING STRIPS
DRUM
AUTOMATIC VALVE
FILTRATE PIPING
CAKE SCRAPER
AIR AND FILTRATE LINE
SLURRY AGITATOR
VAT
SLURRY FEED
AIR BLOW-BACK LINE

Figure IX-1. Cutaway view of a rotary drum vacuum filter.

the upper layer with the aid of a positioned tine bar. The two coil spring layers are then washed separately by spray nozzles and returned to the drum.

sidestreams

The only sidestream is the filtrate which is the liquid removed from the sludge during dewatering. Filtrate is returned to a main plant treatment process. When filtrate quality is poor, it is possible to build up a large proportion of fine solids in the plant and reduce plant treatment efficiency. In an activated sludge process, the filtrate may be returned to a flotation or thickener process.

TYPICAL DESIGN CRITERIA & PERFORMANCE

Performance of the vacuum filtration process can vary widely depending on the sludge type, sludge characteristics, conditioning, type of vacuum filter, and loading rates. Typical applications are shown in Table IX-1 (see following page). These data were summarized from a number of sources including full scale plant operations.

STAFFING REQUIREMENTS

Labor requirements for operation and maintenance of vacuum filters are shown in Table IX-2. The requirements are based on the surface area of the filter.

TABLE IX-2. VACUUM FILTRATION LABOR REQUIREMENTS

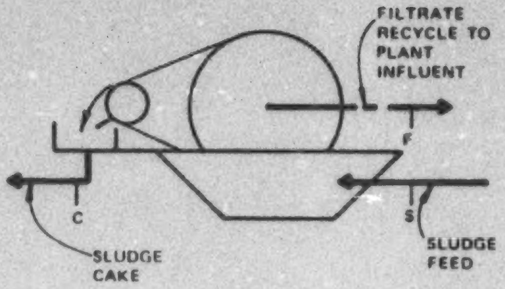
Vacuum filter area, sq ft	Labor, hr/yr Operation	Labor, hr/yr Maintenance	Labor, hr/yr Total
50	1,020	180	1,200
100	1,750	300	2,050
200	2,800	500	3,300
400	4,400	800	5,200
800	7,300	1,300	8,600
1,600	11,900	2,100	14,000
3,200	18,600	3,400	22,000
5,000	25,400	4,600	30,000

TABLE IX-1. VACUUM FILTRATION TYPICAL LOADINGS AND PERFORMANCE

Sludge type	Design assumptions	Feed solids, %	Typical loading rates, psf/hr	Performance cake solids, %
Primary	Thickened to 10% solids polymer conditioned	10	8-10	25-38
Primary + $FeCl_3$	85 mg/l $FeCl_3$ dose Lime conditioning Thickening to 2.5% solids	2.5	1.0-2.0	15-20
Primary + Low Lime	300 mg/l lime dose Polymer conditioned Thickened to 15% solids	15	6	32-35
Primary + High Lime	600 mg/l lime dose Polymer conditioned Thickened to 15% solids	15	10	28-32
Primary + WAS	Thickened to 8% solids Polymer conditioned	8	4-5	16-25
Primary + (WAS + $FeCl_3$)	Thickened to 8% solids $FeCl_3$ & lime conditioned	8	3	20
(Primary + $FeCl_3$) + WAS	Thickened primary sludge to 2.5% Flotation thickened WAS to 5% Dewater blended sludges	3.5	1.5	15-20
Waste Activated Sludge (WAS)	Thickened to 5% solids Polymer conditioned	5	2.5-3.5	15
WAS + $FeCl_3$	Thickened to 5% solids Lime + $FeCl_3$ conditioned	5	1.5-2.0	15
Digested primary	Thickened to 8-10% solids Polymer conditioned	8-10	7-8	25-38
Digested primary + WAS	Thickened to 6-8% solids Polymer conditioned	6-8	3.5-6	14-22
Digested primary + (WAS + $FeCl_3$)	Thickened to 6-8% solids $FeCl_3$ + lime conditioned	6-8	2.5-3	16-18
Tertiary alum	Diatomaceous earth precoat	0.6-0.8	0.4	15-20

MONITORING

		PLANT SIZE (MGD)	TEST FREQUENCY	LOCATION OF SAMPLE	METHOD OF SAMPLE	REASON FOR TEST
SUGGESTED MINIMUM	TOTAL SOLIDS	ALL	1/D	S C	G	P
	BOD	ALL	2/W	F	G	P(1)
	SUSPENDED SOLIDS	ALL	1/D	F	G	P
	FLOW	ALL	R	F	R	P(1)


FILTRATE RECYCLE TO PLANT INFLUENT
F
C
S
SLUDGE CAKE
SLUDGE FEED

A. TEST FREQUENCY

R = RECORD CONTINUOUSLY
D = DAY
W = WEEK

B. LOCATION OF SAMPLE

S = SLUDGE FEED
C = SLUDGE CAKE
F = FILTRATE

C. METHOD OF SAMPLE

G = GRAB SAMPLE
R = RECORD CONTINUOUSLY

D. REASON FOR TEST

P = PROCESS CONTROL

E. FOOTNOTES:

1. FOR CONTROL OF PROCESS RECEIVING THIS FLOW.

NORMAL OPERATING PROCEDURES

Startup

1. Open vacuum and sludge influent valve filtrate flow valve, and chemical conditioning valves.

2. Start up sludge pump, chemical conditioning pump, conditioning tank agitator drive, and filter vat agitator.

3. When sludge nearly fills the filter vat start vacuum pump and filtrate pump.

4. Start drum drive and check drum chain lubricators.

5. Start all other equipment such as wash sprays and conveyor belt drives.

Routine Operations

1. Inspect system twice a shift.

2. Carry out maintenance as required including cleanup and washdown.

3. Take samples as outlined in MONITORING section.

4. Make adjustments in conditioning and drain speed.

Shutdown

1. Shutdown chemical conditioning and sludge feed.

2. Stop filter vat agitator just before vat water level drops below drum.

3. Stop vacuum and filtrate systems.

4. Open drain valves, flush lines, and hose down filter medium and tanks.

5. Stop drum drive and water sprays.

CONTROL CONSIDERATIONS

Physical Control

general Filter physical control is accomplished by drum speed, vacuum, and sludge feed rate. The drum speed is controlled by a variable speed drive.

The vacuum is controlled by:

vacuum control

1. Amount of Conditioning - proper conditioning causes the sludge to release its water allowing the cake to open up and lowering the vacuum requirements.
2. Drum Speed - The slowest drum speed produces the thickest, driest, cake and the lowest vacuum. As the drum speeds up it has less time to remove the water and the vacuum rises with the drum speed.
3. Sludge Level in the Filter Vat - A full vat provides maximum contact time and minimum drying time, resulting in a thicker cake and the highest vacuum. As the vat level is lowered the vacuum drops.
4. Mechanical Devices - Some systems may be equipped with a spring loaded vacuum release valve which can be set to open at any desired vacuum level.

Process Control

yield

Control of the vacuum filter systems should be based on performance. The performance of vacuum filters may be measured by various criteria such as the yield; the efficiency of solids removal and the cake characteristics. Each of these criteria is of importance, but one or the other may be particularly significant in a given plant. Yield is the most common measure of filter performance. The yield is the filter output and is expressed in terms of pounds of dry total solids in the cake discharged from the filter, per square foot of effective filter area per hour.

efficiency

The second measure of filter performance is the efficiency of solids removal. Basically, the vacuum filter is a device used for separating solid matter from liquid, and the actual efficiency of the process is the percentage of feed solids recovered in the filter cake. Solids removals on vacuum filters range from about 85 percent for coarse mesh media to 99 percent with close weave, long nap media. The recycled filtrate solids impose a load on the plant treatment units, and should normally be kept to a practical minimum. However, it may be necessary to reduce the filter efficiency in order to deliver more filter output and thus keep up with sludge production.

The filter cake quality is another measure of filter performance, depending upon cake moisture and heat value. Cake solids content varies from 20 to 40 percent by weight, depending upon the type of sludge handled and the filter cycle time and submergence. Delivery of a very dry cake does *cake*

not necessarily indicate good filter performance. Cake moisture should be adjusted to the method of final disposal; it is inefficient to dry the cake more than is required. When the dewatered sludge is incinerated, a raw sludge cake having a fairly high moisture content can be burned without auxiliary fuel because of the higher volatile content, while a digested sludge cake will have to be drier to burn without make-up heat.

chemical conditioning

If chemical conditioning is used, the operator should determine the best conditioning chemical for the feed sludge. If the character of the feed sludge is subject to change, an evaluation of conditioning agents should be made after each change. Once an effective conditioner has been selected, the next task is to determine the best chemical dosage rate. One or more of the variables should be held constant and the others varied systematically to develop a series of conditioning performance curves. The best chemical conditioning considering cost and required performance can then be determined.

tank agitation

Since all sludges vary, determine the best procedure for operation of the filter vat agitator by experience. Some sludges may require continuous use of the agitator, while others may be best with no vat agitation (in this case the sludge must be without agitation from start-up).

heat treated sludges

The effect of heat treatment on various municipal sludges is to make all types of sludges readily dewaterable by vacuum filtration with minimum chemical conditioning. Raw primary sludges have been dewatered at rates as high as 40 psf/hr and waste activated sludges at 7 psf/hr. Mixtures of raw primary and secondary sludges subjected to heat treatment should produce yields well over 10 psf/hr.

optimum operation

The filter can be operated for maximum sludge cake output, for lowest chemical cost, for the driest cake or any combination of these. All that is necessary is to strike a balance between all the controls for the desired output. Once a balance is achieved, it should be easy to maintain by making small adjustments. Large changes in any one of the operating parameters will effect all the others which means striking a new balance.

cake drying

The sludge cake should not crack until just before it drops off the fabric. This will keep the vacuum pulling air through the sludge, drying it until the last possible moment rather than just pulling air through the cracks.

In general, the filter produces more cake as it runs faster, however, since it is hard to judge production between a thin, fast moving cake, and a thick, dry cake, the pro-

production

duction should be based on the sludge pump speed. The higher sludge pumping rate corresponds to a greater production. The optimum filter drum speed is the fastest speed that will produce a clean discharge of the cake. An exception to this may occur when dewatered sludge is to be incinerated and a very dry cake is desired. In this case, moisture content and incinerator capacity govern the drum speed.

inspection

The quality of the cake should be observed along with the breakup of the cake as it falls from the filter fabric. After gaining some operating experience it should be possible to roughly judge the operation of the filter by visual appearance.

odors

Some odors are generated by the vacuum filtration process, but proper preconditioning, chemical conditioning, and ventilation should minimize the problem.

sampling

Sampling should be performed as outlined under MONITORING. These samples may be obtained through valves provided in the respective thickener piping. If sampling points are not provided, they should be installed to facilitate operation and control of the process. Samples of the supernatant can be obtained at the overflow weir.

analysis

Samples should be analyzed according to procedures specified in Standard Methods.

EMERGENCY OPERATING PROCEDURE

Loss of Power

Short power interruptions should not greatly affect the vacuum filtration system. Although electrical equipment will not operate, the process will not deteriorate if power is regained within about 30 minutes to an hour. During a prolonged outage, septic conditions may develop and it may be advisable to shutdown, drain, and washdown the equipment.

Loss of Other Treatment Units

Loss of treatment units preceding or following the vacuum filter should not affect filter operation significantly except that the performance or yield may change.

COMMON DESIGN SHORTCOMINGS

Shortcoming	Solution
1. Improper filter media specified with result that (a) filter blinds or (b) has inadequate solids capture.	1. Run filter leaf tests with different media. Replace media with best one.
2. Improper chemical conditioning system specified.	2. Run filter leaf tests to determine proper conditioning chemical and dosage.
3. No provisions for cleaning of filtrate lines.	3. Install unions or tees in filtrate line to permit ready cleaning.
4. Cake does not release well from belt-type filter.	4. Add blade to supplement discharge roll.
5. Filtrate pumps are easily air bound.	5. Install an equalizing line from high point of receiver to the top of the pump casing.

TROUBLESHOOTING GUIDE

VACUUM FILTRATION

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. High solids in filtrate.	1a. Improper coagulant dosage.	1a. Coagulant dosage.	1a. Change coagulant dosage.
	1b. Filter media blinding.	1b. Coagulant feeder calibration.	1b. Recalibrate coagulant feeder.
		1c. Visually inspect media.	1c. Synthetic cloth - detergent and steam wash steel coils - acid clean cloth-water wash or exchange for new.
2. Thin cake with poor dewatering.	2a. Filter media blinding.	2a. Inspect media.	2a. See 1b.
	2b. Improper chemical dosage.	2b. See 1a.	2b. See 1a.
	2c. Inadequate vacuum.	2c. Amount of vacuum, leaks in vacuum system, leaks in seals.	2c. Repair vacuum system (See 3 also).
	2d. Drum speed too high.	2d. Drum speed.	2d. Reduce drum speed.
	2e. Drum submergence too low.	2e. Drum submergence.	2e. Increase drum submergence.
3. Vacuum pump stops.	3a. Lack of power.	3a. Heater tripped.	3a. Reset pump switch.
	3b. Lack of seal water.	3b. Source of seal water.	3b. Start seal water flow.
	3c. Broken V-belt.	3c. V-belt.	3c. Replace V-belt.
4. Drum stops rotating.	4a. Lack of power.	4a. Heater tripped.	4a. Reset drum rotation switch.
5. Receiver is vibrating.	5a. Filtrate pump is clogged.	5a. Filtrate pump output.	5a. Turn pump off and clean.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	5b. Loose bolts and gasket around inspection plate.	5b. Inspection plate.	5b. Tighten bolts and align gasket.
	5c. Worn ball check in filtrate pump.	5c. Ball check.	5c. Replace ball check.
	5d. Air leaks in suction line.	5d. Suction line.	5d. Seal leaks.
	5e. Dirty drum face.	5e. Drum face.	5e. Clean face with pressure hose.
	5f. Seal strips missing.	5f. Drum.	5f. Replace seal strips.
6. High vat level.	6a. Improper chemical conditioning.	6a. Coagulant dosage.	6a. Change coagulant dosage.
	6b. Feed rate too high.	6b. Feed rate and solids yield.	6b. Reduce feed rate.
	6c. Drum speed too slow.	6c. Drum speed.	6c. Increase drum speed.
	6d. Filtrate pump off or clogged.	6d. Filtrate pump.	6d. Turn on (or clean) pump.
	6e. Drain line plugged.	6e. Drain line.	6e. Clean drain line.
	6f. Vacuum pump stopped.	6f. See item 3.	6f. See item 3.
	6g. Seal strips missing.	6g. Drum	6g. Replace seal strips.
7. Low vat level.	7a. Feed rate too low.	7a. Feed rate.	7a. Increase feed rate.
	7b. Vat drain valve open.	7b. Vat drum valve.	7b. Close vat drain valve.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
8. High amperage draw by vacuum pump.	8a. Filtrate pump clogged.	8a. Filtrate pump output.	8a. Turn pump off and clean.
	8b. Improper chemical conditioning.	8b. Coagulant dosage.	8b. Change coagulant dosage.
	8c. High vat level.	8c. See item 6.	8c. See item 6.
	8d. Cooling water flow to vacuum pump to high.	8d. Cooling water flow.	8d. Decrease cooling water flow.
9. Scale buildup on vacuum pump seals.	9a. Hard, unstable water.	9a. Vacuum pump seals.	9a. Add a scale inhibitor.

MAINTENANCE CONSIDERATIONS

A good preventive maintenance program will reduce breakdowns which could be not only costly, but also very unpleasant for operating personnel. Plant components including the following should be inspected semiannually for wear, corrosion, and proper adjustment:

mechanical

1. Drives and gear reducers
2. Drive chains and sprockets
3. Shaft bearings and bores
4. Bearing brackets
5. Baffles and weirs
6. Electrical contacts in starters and relays
7. Suction lines and sumps
8. Vacuum pump or system

SAFETY CONSIDERATIONS

At least two persons should be present when working in areas not protected by handrails. Walkways and work areas should be kept free of grease, sludge, oil, leaves and snow. Protective guards and covers must be installed unless mechanical/electrical equipment is locked out of operation. Avoid acid cleaning of filtrate lines because of the potential for explosions.

REFERENCE MATERIAL

References

1. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, 1015 Eighteenth Street, N.W., Washington, D.C. 20036.

2. WPCF Manual of Practice No. 17 (WPCF MOP No. 17), Paints and Protective Coatings for Wastewater Treatment Facilities.

3. WPCF Manual of Practice No. 20, Chapter 4, Sludge Dewatering.

Glossary of Terms and Sample Calculations

1. Solids content, also called percent total solids, is the weight of total solids in sludge per unit total weight of sludge, expressed in percent. Water content plus solids content equals 100 percent. This includes all chemicals and other solids added to the sludge.

2. Sludge concentration is the weight of solids per unit weight of sludge. It can be calculated in percent as follows:

$$\text{Concentration} = \frac{\text{weight of dry sludge solids}}{\text{weight of wet sludge}} \times 100$$

3. Loading rate is the loading of the dry weight basis sludge solids divided by the area of the vacuum filter drum. The dry weight of the solids must include chemicals that are added.

4. Filtrate is the effluent or liquid portion of a sludge removed by or discharged from a filter.

X

PRESSURE FILTRATION

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PROCESS DESCRIPTION

There are several types of presses available but the most common consists of vertical plates which are held in a frame and which are pressed together between a fixed and moving end as shown in Figure X-1 (see following page). A cloth is mounted on the face of each individual plate. Despite its name, the filter press does not close to squeeze or press sludge. Instead, the press is closed and then sludge is pumped into the press at pressures up to 225 psi and passes through feed holes in the trays along the length of the press. Filter presses usually require a precoat material (incinerator ash or diatomaceous earth are typically used) to aid in solids retention on the cloth and release of the cake.

process

The water passes through the cloth, while the solids are retained and form a cake on the surface of the cloth. Sludge feeding is stopped when the cavities or chambers between the trays are filled. Drainage ports are provided at the bottom of each press chamber. The filtrate is collected in these, taken to the end of the press, and discharged to a common drain.

operation

The dewatering step is completed when the filtrate flow is near zero. At this point the pump feeding sludge to the press is stopped and any back pressure in the piping is released through a bypass valve. The electrical closing gear is then operated to open the press. The individual plates are next moved in turn over the gap between the plates and the moving end. This allows the filter cakes to fall out. The plate moving step can be either manual or automatic. When all the plates have been moved and the cakes released, the complete rack of plates is then pushed back by the moving end and closed by the electrical closing gear. The valve to the press is then opened, the sludge feed pump started, and the next dewatering cycle commences. Filter presses are normally installed well above floor level, so that the cakes can drop onto conveyors or trailers positioned underneath the press.

Filtrate quality should be very good (less than 100 mg/l suspended solids) if the system is properly operated. During the early part of the cycle, the drainage from a large press can be in the order of 2,000 to 3,000 gallons per hour. This rate falls rapidly to about 500 gallons per hour as the

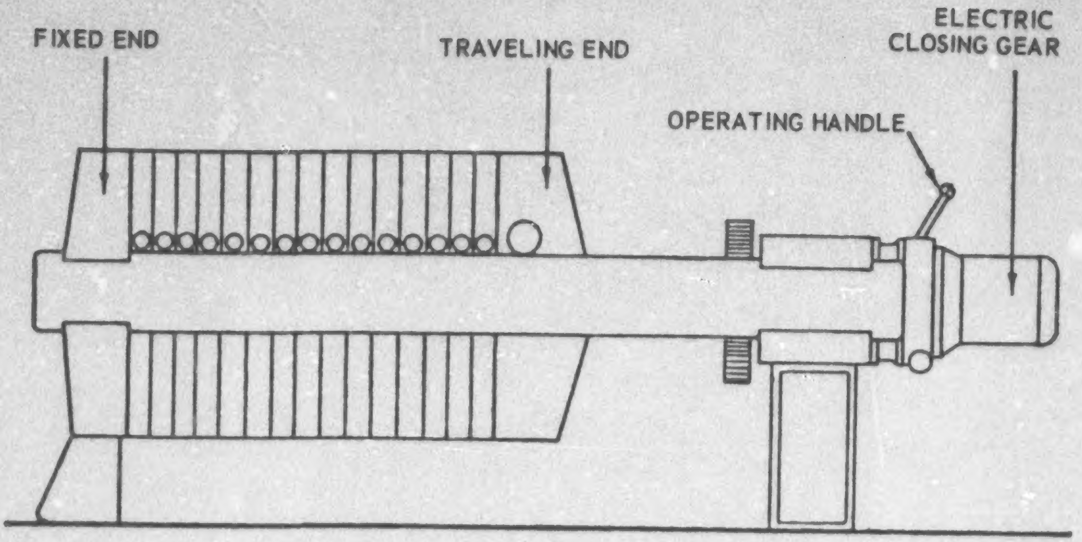


Figure X-1. Side view of a filter press.

cake forms and at the end of the cycle the rate is virtually zero. Filtrate is normally returned to the plant treatment process.

design differences

One modification to the filter press is a vertical press with horizontal pressing modules. An endless filter cloth passes through the stacked modules and then through a washing chamber. Each module forms a cavity and is designed with a sealing mechanism at the end opposite the point of feed. The sealing mechanism is lowered onto the cloth during the charging and pressing cycles and retracts during the discharging cycle. Once the pumps have filled the modules with sludge, an impervious diaphragm at the top of each module is pneumatically activated to squeeze the water from the sludge. After the dewatering step, the filter cloth advances to remove the cake from the modules. Although the unit has a much smaller filter area than the filter leaf press, reasonable yields are possible because of the reduced cycle time.

The pressures which may be applied to a sludge for removal of water by filter presses now available range from 5,000 to 20,000 times the force of gravity. In comparison, a solid bowl centrifuge provides forces of 700 to 3,500 times the force of gravity and a vacuum filter, 1,000 times the force of gravity. As a result of these greater pressures, filter presses may provide higher cake solids concentrations

(30 to 50 percent solids) at reduced chemical dosage. In some cases, ash from a downstream incinerator is recycled as a sludge conditioner.

TYPICAL DESIGN CRITERIA AND PERFORMANCE

Typical loading rates and results from pressure filtration of various sludges are shown in Table X-1 (see following page). This data was developed from "Process Design Manual for Sludge Treatment and Disposal", (EPA 625/1-74-006). Typical performance criteria are the pressing cycle length, the solids content of the cake, and the quality of the filtrate. Performance of filter press on various sludges will vary widely, but the data in Table X-1 are typical.

STAFFING REQUIREMENTS

Labor requirements for operation and maintenance of manual filter presses are shown in Table X-2. The requirements are based on the displacement (size) of the press and continuous operation with a two hour cycle. The labor requirements were developed from actual plant operation experience.

TABLE X-2. FILTER PRESS LABOR REQUIREMENTS

Filter press volume, cu ft	Labor, hr/yr		
	Operation	Maintenance	Total
Less than 50	6,000	1,500	7,500
100	6,500	1,600	8,100
200	8,400	2,100	10,500
400	13,600	3,400	17,000
800	26,400	6,600	33,000

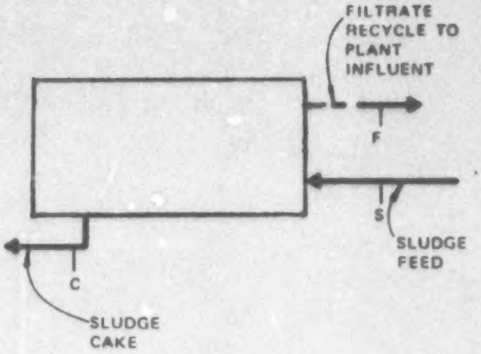
TABLE X-1. TYPICAL RESULTS PRESSURE FILTRATION

Sludge type	Conditioning	Feed solids, %	Typical cycle length, hr	% solids filter cake solids, %
Primary	5% $FeCl_3$, 10% Lime	5	2	45
	100% Ash		1.5	50
Primary + $FeCl_3$	10% Lime	4*	4	40
Primary + 2 stage high lime	None	7.5	1.5	50
Primary + WAS	5% $FeCl_3$, 10% Lime	8*	2.5	45
	150% Ash		2.0	50
Primary + (WAS $FeCl_3$)	5% $FeCl_3$, 10% Lime	8*	3	45
(Primary + $FeCl_3$) + WAS	10% Lime	3.5*	4	40
WAS	7.5% $FeCl_3$, 15% Lime	5*	2.5	45
	250% Ash		2.0	50
WAS + $FeCl_3$	5% $FeCl_3$, 10% Lime	5*	3.5	45
Digested Primary	6% $FeCl_3$, 30% Lime	8	2	40
Digested Primary + WAS	5% $FeCl_3$, 10% Lime	6-8*	2	45
	100 % Ash		1.5	50
Digested Primary + (WAS + $FeCl_3$)	5% $FeCl_3$, 10% Lime	6-8*	3	40
Tertiary Alum	10% Lime	4*	6	35
Tertiary Low Lime	None	8*	1.5	55

* Thickening used to achieve this solids concentration.

MONITORING

		PLANT SIZE (MGD)	TEST FREQUENCY	LOCATION OF SAMPLE	METHOD OF SAMPLE	REASON FOR TEST
SUGGESTED MINIMUM	TOTAL SOLIDS	ALL	1/D	S C	G	P
	BOD	ALL	2/W	F	G	P(1)
	SUSPENDED SOLIDS	ALL	1/D	F	G	P
	FLOW	ALL	R	F	R	P(1)


FILTRATE RECYCLE TO PLANT INFLUENT
F
S
SLUDGE FEED
C
SLUDGE CAKE

A. TEST FREQUENCY

R = RECORD CONTINUOUSLY
D = DAY
W = WEEK

B. LOCATION OF SAMPLE

S = SLUDGE FEED
C = SLUDGE CAKE
F = FILTRATE

C. METHOD OF SAMPLE

G = GRAB SAMPLE
R = RECORD CONTINUOUSLY

D. REASON FOR TEST

P = PROCESS CONTROL

E. FOOTNOTES:

1. FOR CONTROL OF PROCESS RECEIVING THIS FLOW.

NORMAL OPERATING PROCEDURES

Startup

1. Check the plates to make sure they are aligned properly, that fabric is in place, and that there are no obstructions to operation.

2. For safety, filter press installations are usually equipped with a photo-electric light that surrounds the press and stops the closing mechanism if the light beam is interrupted. This system must be checked for proper operation:

   a. Check that the light curtain is illuminated after switching it on.

   b. Check that the closing motor stops when the light beam is blocked.

3. Close the press. The press is usually closed by advancing the control handle forward. The press will continue to run until it is fully closed and disengages itself from the driving gear box. At this point a change in pitch of the motor whine will be heard.

   Several manufacturers suggest the following procedure to insure that the press is completely closed and safe before sludge feed. If cast iron plates are used, pull back the control handle to the central position, cutting off the motor momentarily, then restart again by advancing the handle forward just once for a short burst. This will insure that the press is completely home. If rubber trays are used repeat this closing procedure two or three times.

4. Start sludge feed pump(s).

5. Start up chemical conditioning.

Routine Operations

1. Inspect system regularly as the cycle progresses.

2. Carry out maintenance as required including cleanup and washdown.

3. Take samples as outlined in MONITORING section.

Cake Discharge

1. Monitor the cycle progress to determine when the cycle is complete and the cake is ready for discharge from the press.
2. Before opening the press, shutdown the feed to that press and the chemical conditioning if necessary. Be sure that all valves are closed, and there is no pressure indicated on the pressure gauge.
3. Move the operating level to the "open" position. This displaces the moving end back to its final position and starts the tray or plate moving mechanism. The plates are opened one at a time allowing the operator to observe the cake discharge.
4. If there is any cake remaining on a cloth the operator may step into the light curtain which stops the press and allows him to clean that cloth. The press will restart when the operator moves out of the light curtain.
5. Care should be taken during discharge to ensure that no cake sticks to the gasket area of the cloth and that the cloths are not wrinkled on the gasket area.
6. After the last plate has been moved and the cake discharged, close the press as outlined under "startup" in preparation for the next cycle.
7. When discharging the press, check each plate feed port to be sure it is not plugged. A blocked feed port will starve the plate(s) resulting in uneven pressures and possible damage to the mechanism.

Shutdown

1. Run the press through a "cake discharge cycle". For press shutdown ensure that all feed lines are rinsed, that all filter cloths and plate gaskets are clean and that the plate feed eyes are clear. Turn off light curtain and power to press.
2. Wash down all plates, fabric, and parts of the press carefully.
3. Rinse out feed lines.
4. Turn off light curtain and power to the press.

CONTROL CONSIDERATIONS

Physical Control

Instrumentation is usually minimal, however, it is possible to completely automate the operation of the filter press if desired. Pressure gauges should be provided to monitor the feed pressures and the filtrate flow must be monitored either visually or with a flow indicator.

Process Control

moisture control

If the filter press is operated as recommended with sufficient washing and air drying time between cycles, the cake should have the highest possible solids content. It should discharge from the press with a minimum of debris left behind. Discharge of a wet cake can lead to dirty cloths on the lower stile faces making it difficult to obtain a good seal on this gasket area when closing the press.

filtrate flow

It is usually possible to develop an excellent relationship between filtrate flow rate (which decreases as the cycle progresses) and cake moisture for a given sludge. That is, for any given filtrate flow rate, a corresponding filter cake concentration can be expected.

precoat

Whether or not to precoat is an operational question. The precoat is the placement of an initial coating on the filter cloth prior to application of the sludge. The precoat acts as an additional filtration membrane and also aids in a clean removal of sludge from the cloth. If the investment in a precoat system has been made, its use should reduce manpower requirements for media cleaning and may provide better performance.

cloth characteristics

If the press is operated as recommended, but performance is unsatisfactory a different type of cloth may give better results. This is unlikely to happen, however, other cloth types can be tried until the desired performance is obtained. The addition of precoat may also aid in performance.

sampling

Sampling should be performed as outlined under MONITORING. These samples may be obtained through valves provided in the respective piping or directly from the process. If sampling points are not provided, they should be installed to facilitate operation and control of the process.

analysis

Samples should be analyzed according to procedures specified in Standard Methods.

EMERGENCY OPERATING PROCEDURES

Loss of Power

A loss of power will not adversely affect the performance of the filter press except to interrupt its operation. During opening or closing of the press return the control lever to its neutral position until power is restored then continue operation.

Loss of Other Treatment Units

The operation and performance of other treatment units has little affect on the operation of filter press. Performance however, may be somewhat affected by a reduced solids concentration of the incoming sludge.

COMMON DESIGN SHORTCOMINGS

Shortcoming	Solution
1. Gravimetric Ash Feeders Installed - bulking problems with ash.	1. Install Volumetric Feeders.
2. Cake transport system inadequate (screw conveyors plug; belt conveyor limited to 15° slope).	2. Install heavy-duty flight conveyor.
3. Mechanical Ash Conveyor Installed - noise and maintenance problems.	3. Install pneumatic ash conveying system.
4. Improper media specified - poor cake discharge, difficult to clean.	4. Change media; usually a relatively coarse monofilament media is used on municipal sludges.

TROUBLESHOOTING GUIDE

PRESSURE FILTRATION

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Plates fail to seal.	1a. Poor alignment.	1a. Alignment	1a. Realign plates.
	1b. Inadequate shimming.	1b. Stay bosses.	1b. Adjust shimming of stay bosses.
2. Cake discharge is difficult.	2a. Inadequate precoat.	2a. Prevent feed.	2a. Increase percoat, feed @ 25-40 psig.
	2b. Improper conditioning.	2b. Conditioner type and dosage.	2b. Change conditioner type on dosage based on filter leaf tests.
3. Filter cycle times excessive.	3a. Improper conditioning.	3a. Chemical dosage.	3a. Change chemical dosage.
	3b. Feed solids too low.	3b. Operation of thickening processes.	3b. Improve solids thickening to increase solids concentration in press feed.
4. Filter cake sticks solids conveying equipment.	4a. Change chemical conditioning by using more inorganic chemicals.	4a. Conditioning dosage.	4a. Decrease ash, increase inorganic conditioners.
5. Precoat pressures gradually increase.	5a. Improper sludge conditioning.	5a. Conditioning dosages.	5a. Change chemical dosage.
	5b. Improper precoat feed.	5b. Precoat feed.	5b. Decrease precoat feed substantially for a few cycles, then optimize.
	5c. Filter media plugged.	5c. Filter media.	5c. Wash filter media.
	5d. Calcium buildup in media.		5d. Acid wash media (inhibited muriatic acid).

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
6. Frequent media binding.	6a. Precoat inadequate.	6a. Precoat feed.	6a. Increase precoat.
	6b. Initial feed rates too high (where no precoat used).		6b. Develop initial cake slowly.
7. Excessive moisture in cake.	7a. Improper conditioning.	7a. Conditioning dosage.	7a. Change chemical dosage.
	7b. Filter cycle too short.	7b. Correlate filtrate flow rate with cake moisture content.	7b. Lengthen filter cycle.
8. Sludge blowing out of press.	8a. Obstruction, such as rags, in the press forcing sludge between plates.		8a. Shutdown feed pump, hit press closure drive, re-start feed pump - clean feed eyes of plates at end of cycle.
9. Leaks around lower faces of plates.	9a. Excessive wet cake soiling the media on lower faces.	9a. Cake moisture content.	9a. See item 7.

MAINTENANCE CONSIDERATIONS

A good preventive maintenance program will reduce breakdowns which could be not only costly, but also very unpleasant for operating personnel. Plant components including the following should be inspected semi-annually for wear, corrosion, and proper adjustment.

mechanical

1. Drives and gear reducers
2. Drive chains and sprockets
3. Closing mechanism
4. Bearing brackets
5. Electrical contacts in starters and relays
6. Suction lines and sumps

cloth washing

Occasionally it may be necessary to wash the cloths in place. When this is done the cloths or media should be pulled square and free of any creases. A hand-held, high pressure, single jet (about 750 psi) is usually effective for cleaning of the media. A plastic cover draped over the filter will be needed to confine spray during the cleaning cycle. Mechanized washing arrangements are available for some filters. Where acid washing is provided, a recirculating system provides both a scrubbing and acid effect as opposed to merely soaking the media in acid.

rubber

The rubber surfaces of the plates should be scraped only with soft plastic or wood to avoid damage.

SAFETY CONSIDERATIONS

Filter presses are normally equipped with a light curtain which automatically shuts down the plate shifting cycle if someone falls or reaches into the machine. Face shields and rubber gloves should be worn during acid cleaning of media. The feed pumps develop high pressures and the press should not be opened until these pressures are relieved.

REFERENCE MATERIAL

References

1. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, 1015 Eighteenth Street, N.W., Washington, D.C. 20036.

2. WPCF Manual of Practice No. 17 (WPCF MOP No. 17), Paints and Protective Coatings for Wastewater Treatment Facilities.

Glossary of Terms and Sample Calculations

1. Solids content, also called percent total solids, is the weight of total solids in sludge per unit total weight of sludge, expressed in percent. Water content plus solids content equals 100 percent. This includes all chemicals and other solids added to the sludge.

2. Sludge concentration is the weight of solids per unit weight of sludge. It can be calculated in percent as follows:

$$\text{concentration} = \frac{\text{weight of dry sludge solids}}{\text{weight of wet sludge}} \times 100$$

XI

BELT FILTRATION

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PROCESS DESCRIPTION

Several types of dewatering devices are included in this section:

Moving screen concentrators
Belt pressure filters
Capillary dewatering systems
Rotary gravity concentrators

process

These systems attempt to overcome the sludge pick-up problem occasionally experienced with rotary vacuum filters. A combination of sludge conditioning, gravity dewatering and pressure dewatering is utilized to increase the solids content of either digested or undigested sludge. Sludge conditioning, usually with polymers, may not be necessary with some types of easily dewatered sludges such as raw primary.

In all these units, the influent mixture of solids and polymer (or other chemical) is placed onto a moving porous belt or screen. Dewatering occurs as the sludge moves through a series of rollers which squeeze the sludge to the belt or squeeze the sludge between two belts much like an old washing machine wringer. The cake is discharged from the belt by a scraper mechanism.

design differences

Many physical differences exist between various belt filters. For example, the type of filtration belt used for each unit varies in size, porosity and material. The operator should note the specific operation and maintenance requirements of the equipment at his plant. Flow schematics for some of the various designs are shown in Figures XI-1 through XI-4 (see following pages).

filtrate return to process

Filtrate from the belt filtration unit is usually returned either to the primary or secondary treatment process and normally causes no problem to process operation.

TYPICAL DESIGN CRITERIA AND PERFORMANCE

Belt filtration units are usually designed on the basis of the sludge feed rate. Most manufacturers offer several unit sizes that will handle various sludge feed rates. Typically, the plant requirements, depending on the quantity and type of sludge, are matched to one or more of the unit

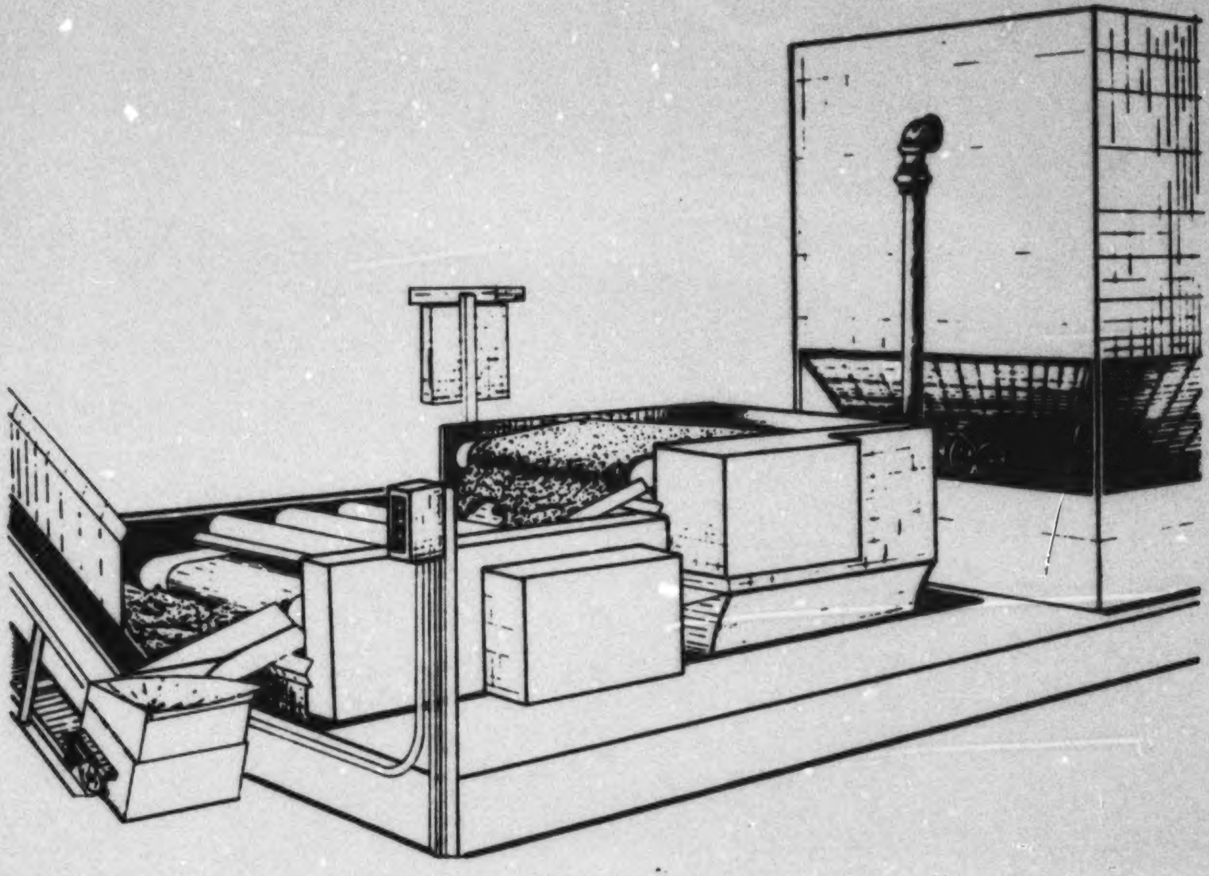


Figure XI-1. Moving screen concentrator.

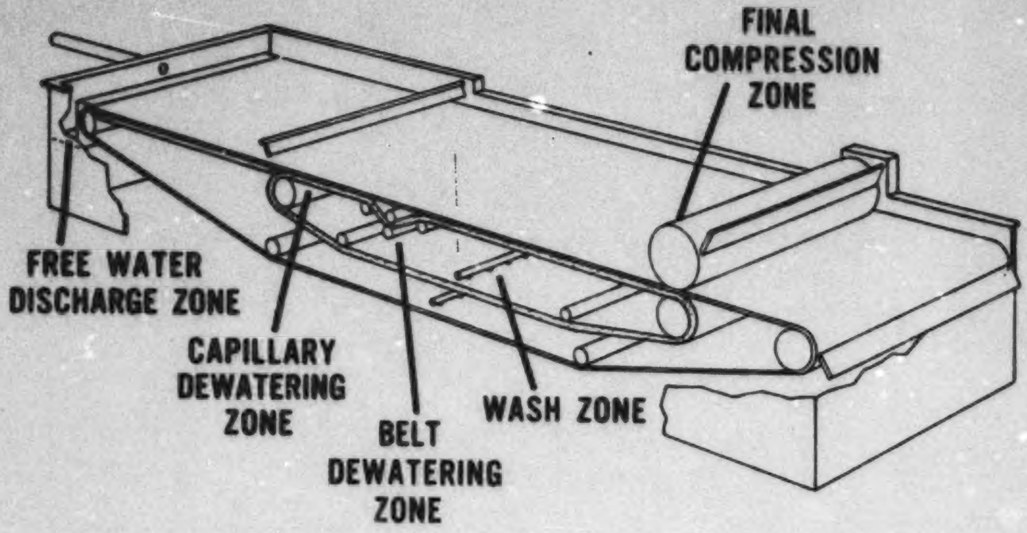

FINAL
COMPRESSION
ZONE
FREE WATER
DISCHARGE ZONE
CAPILLARY
DEWATERING
ZONE
BELT
DEWATERING
ZONE
WASH ZONE

Figure XI-2. Capillary dewatering system.

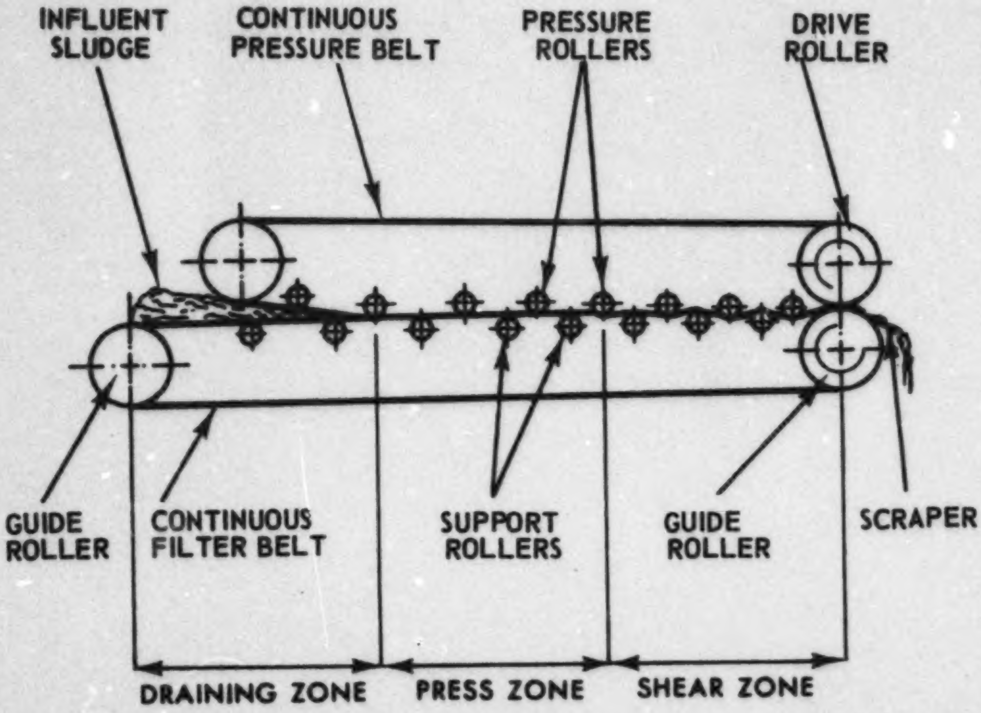
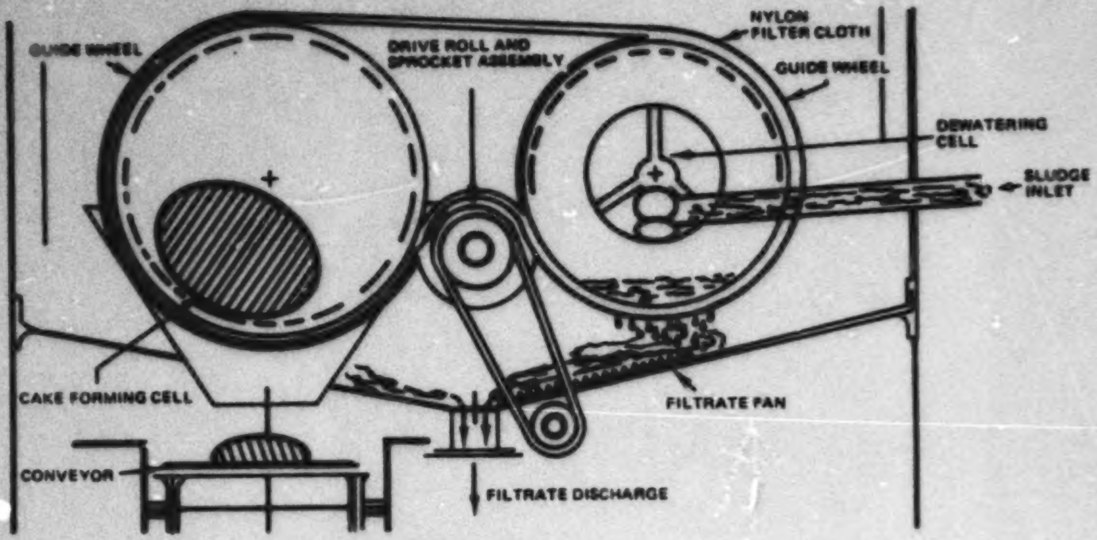
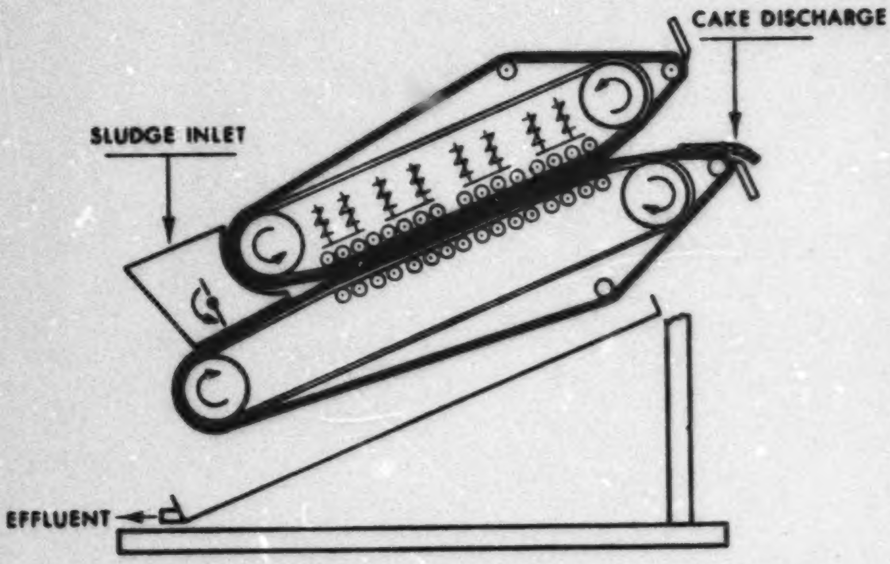

INFLUENT
SLUDGE
CONTINUOUS
PRESSURE BELT
PRESSURE
ROLLERS
DRIVE
ROLLER
GUIDE
ROLLER
CONTINUOUS
FILTER BELT
SUPPORT
ROLLERS
GUIDE
ROLLER
SCRAPER
DRAINING ZONE
PRESS ZONE
SHEAR ZONE

Figure XI-3. Belt pressure filter.


GUIDE WHEEL
DRIVE ROLL AND SPROCKET ASSEMBLY
NYLON FILTER CLOTH
GUIDE WHEEL
DEWATERING CELL
SLUDGE INLET
CAKE FORMING CELL
FILTRATE PAN
CONVEYOR
FILTRATE DISCHARGE

Concentrator


CAKE DISCHARGE
SLUDGE INLET
EFFLUENT

Multiroll press

Figure XI-4. Dual cell gravity concentrator.

sizes available from the manufacturer.

Reported performance from actual installations for belt filtration units are shown in Table XI-1.

TABLE XI-1. BELT FILTRATION UNIT PERFORMANCE

Sludge type	Influent sludge solids, %	Sludge cake solids, %
Moving screen concentrator		
Activated	0.5-1.0	8-10
Primary		20-30
Belt pressure filters		
Primary	5.7	19
Capillary dewatering systems		
Activated	1.0-1.5	15-18
Dual cell gravity with multiroll press		
Raw primary	3	20-23
Digest	0.5-4.0	16-20
WAS	1.9-3.0	18-23

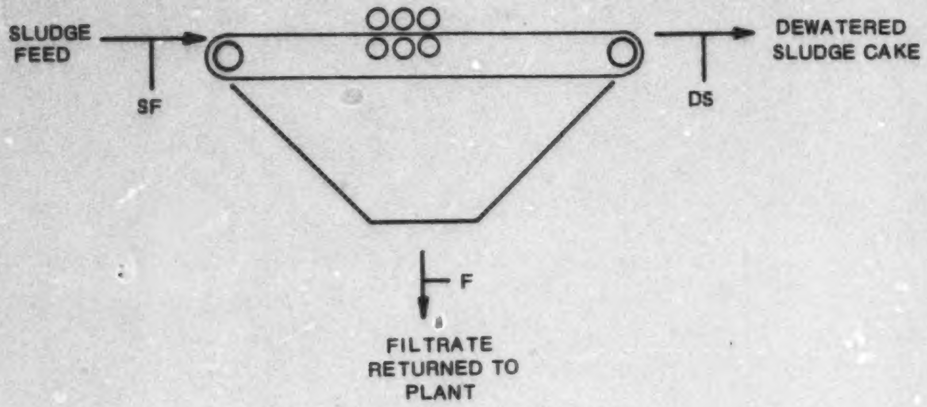
STAFFING REQUIREMENTS

Labor requirements for operation and maintenance of belt filtration units are shown in Table XI-2. The requirements are based on the number of units in use at the plant and include periodic operational adjustments and minor routine maintenance. Removal of sludge is not included. Labor requirements are based on experience at actual installations.

TABLE XI-2. BELT FILTRATION UNIT LABOR REQUIREMENTS

Number of units	Labor, hr/yr		
	Operation	Maintenance	Total
1	265	100	365
2	530	200	730
3	795	300	1,095
4	1,060	400	1,460
5	1,325	500	1,825

MONITORING


SLUDGE FEED
SF
DEWATERED SLUDGE CAKE
DS
F
FILTRATE RETURNED TO PLANT

SUGGESTED MINIMUM

	TEST FREQUENCY	LOCATION OF SAMPLE	METHOD OF SAMPLE	REASON FOR TEST
TOTAL SOLIDS	1/D	SF, DS	G	P
BOD	2/W	F	G	P
SUSPENDED SOLIDS	1/D	F	G	P
FLOW	R	F	R	P

A. TEST FREQUENCY

R = RECORD CONTINUOUSLY
D = DAY
W = WEEK

B. LOCATION OF SAMPLE

SF = SLUDGE FEED
DS = DEWATERED SLUDGE
F = FILTRATE

C. METHOD OF SAMPLE

G = GRAB SAMPLE
R = RECORD CONTINUOUSLY

D. REASON FOR TEST

P = PROCESS CONTROL

NORMAL OPERATING PROCEDURES

Startup

1. Belt filtration equipment should be inspected and operated to make certain that installation is correct, proper clearance and adjustments have been made, and that belt tracks properly.
2. Check chemical tank and mixing apparatus to assure that enough chemical is available for completion of the run.
3. Set sludge and chemical pumps to the predetermined rate.
4. Start dewatering unit.
5. Start spray water.
6. Start sludge and chemical pumps.
7. Adjust speed of belts or screens, chemical pumping rate and sludge pumping rate as necessary to establish a balance of flow.

Routine Operations

1. Inspect system at least twice per shift.
2. Check tracking of filter belt, adjust if necessary.
3. Carry out maintenance as required including cleanup and washdown.
4. Take samples as outlined in MONITORING Section.

Shutdown

1. Inspect system at least once per shift.
2. Shutdown sludge and chemical pumps.
3. Shutdown the dewatering unit.
4. Turn off water sprays.
5. Drain sludge and water from unit and clean thoroughly with hose.

CONTROL CONSIDERATIONS

Physical Control

belt tracking

Correct tracking of the filter belt is very important to assure minimum wear and damage to the belts. Some units are equipped with automatic adjusting devices designed to correct roller alignment automatically. Other units require a periodic check and adjustment, if necessary, to be made by the plant operator.

spray adjustment

Correct adjustment of spray nozzles used to clean the underside of the belt or screen is also important. Sludge buildup on the underside of the belt creates a tracking problem. Just enough spray should be used so that the underside of the belt remains clean.

Process Control

inspection

The filtrate should be relatively clear and no excessive sludge buildup should be occurring anywhere along the belt or rollers. Once the operator is familiar with this equipment it should be possible to judge the operation of the belt filtration unit by visual appearance.

sampling

Sampling should be performed as outlined under MONITORING. Influent sludge and filtrate samples may be obtained through valves provided. Dewatered sludge samples may be obtained after the sludge has been removed from the belt by the scraper mechanism.

analysis

Samples should be analyzed according to procedures specified in Standard Methods.

sludge conditioning

Proper sludge conditioning is an important step in any sludge dewatering process. Sludge conditioning results in flocculation of the small sludge particles into larger particles which have enough size and strength to bridge the openings in the filter belt and, thus, be retained on that belt.

In order to determine the best chemicals and chemical dosages to use, jar testing should be performed on several sludge samples. The optimum dosage will be that above which little or no increase in floc size or supernatant clarity is noted.

In addition to the chemicals, the following parameters will affect the final percent solids concentration obtained by the belt filtration unit:

1. Incoming sludge percent solids
2. Loading or application rate (lb/hr) of sludge to belt filtration unit
3. Operating speed of belt filtration unit
4. Compression of the pressure rollers

solids

In general, a thicker incoming sludge will produce a drier cake. However, varying the initial solids concentration is not normally used as a process control variable. It is customary, unless special conditions apply, to deliver as thick a sludge as practical to the belt filtration unit.

loading rate

The sludge loading rate or application rate has a significant affect on the performance of the belt filtration unit.

A loading rate that is too high will cause poor performance. The ideal loading rate is the highest rate at which the system can be run without a drop in the desired performance. This rate is dependent on the rate of travel of the filter belt.

belt rate of travel

The speed of the filter belt should be increased along with a corresponding increase in the rate of sludge feed. The exact speed at which the unit should be operated depends on the results desired in terms of sludge cake dryness, of percent sludge retained on the filter belt, and the dewatering rate of the sludge. This speed can only be determined by trial and error operation. Once this setting has been determined, infrequent minor adjustments should be required. If the unit is to be shut down, these settings should be noted for use when restarting.

compression

Determination of the best compression of the pressure rollers may require a certain amount of experimentation through actual operation to set properly. Once set they should require little adjustment.

EMERGENCY OPERATING PROCEDURES

Loss of Power

Belt filtration units will not operate during power interruptions. During a power loss, shutdown procedures should be followed, including washing down of equipment to prevent any clogging from dried sludge. When power is restored, normal startup procedure should be followed.

Loss of Other Treatment Units

Loss of other treatment units should not greatly affect the operation of the belt filtration unit. Performance may be affected and process readjustment required if the malfunctioning process causes a decrease in the percent solids of the sludge pumped to the belt filtration unit.

COMMON DESIGN SHORTCOMINGS

Shortcoming	Solution
1. Corrosion of steel components.	1. Coat surfaces with proper paint. Industrial paint suppliers and appliers can be located in the yellow pages of large city telephone directories. These suppliers can furnish complete recommendations on proper coating systems for various application. See also WPCF MOP No. 17.
2. Filter belt creeps off rollers, will not track properly.	2. Check automatic tracking device, if one exists, for proper operation. Check bottom of filter belt and surface of drive roller for sludge buildup. If buildup occurs, water spray is not adequate. Increase spray pressure or install new spray heads.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Dewatered sludge not thick enough.	1a. Sludge application rate too high.	1a. Check sludge pumping rate.	1a. Adjust influent sludge pumping rate.
	1b. Belt speed too high.	1b. Check belt speed.	1b. Adjust belt speed.
	1c. Incorrect polymer dose.	1c. Check polymer mixing and dose.	1c. If polymer dose is much less or much greater than the ideal dose, performance will decrease. Use jar test procedure to determine optimum dose.
2. Excessive belt wear.	2a. Improper alignment of rollers.	2a. Check tracking of belt to see if it creeps off to one side.	2a. Adjust alignment of rollers.
	2b. Sludge buildup on bottom of belt or on rollers causing improper alignment.	2b. Check operation of automatic belt adjustor.	2b. Replace or repair faulty adjustor mechanism.
		2c. Check bottom of belt.	
3. Solids in filtrate.	3a. Incorrect polymer dose.	3a. Check polymer mixing and dose.	3a. Use jar test to determine optimum dose.
	3b. Solids running off the edge of the filter belt.	3b. Check influent sludge pumping rate.	3b. Reduce sludge pumping rate accordingly.
		3c. Check belt rate of travel.	3c. Adjust belt rate of travel as required.
4. Oil leak.	4a. Oil seal failure.	4a. Check oil seal.	4a. Replace seal.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
5. Noisy or hot bearings or universal joint.	5a. Excessive wear. 5b. Improper alignment. 5c. Lack of lubrication.	5a. Alignment. 5b. Lubrication.	5a. Replace, lubricate, or align joint or bearing as required.

MAINTENANCE CONSIDERATIONS

A good preventative maintenance program will reduce breakdowns which could be not only costly, but also very unpleasant for operating personnel. Plant components including the following, should be inspected semiannually for wear, corrosion, and proper adjustment.

mechanical

1. V-belts, drives, and gear reducers
2. Porous filter belts
3. Rollers, shaft bearings, and bores
4. Bearing brackets
5. Baffles
6. Electrical contacts in starters and relays
7. Suction lines and pumps
8. Chemical mixing pumps and tanks

SAFETY CONSIDERATIONS

Hands and arms should be kept away from moving belts and rollers. Loose clothing is a hazard and may get caught in these rotating parts. Always be certain protective guards and covers are in place unless mechanical/electrical equipment is locked out of operation. Work areas and walkways should be kept free of grease, oil, leaves, snow, and sludge.

REFERENCE MATERIAL

References

1. Standard Methods for the Examination of Water and Wastewater.
   American Public Health Association
   1015 Eighteenth Street, N.W.
   Washington, D.C. 20036

2. WPCF Manual of Practice No. 17
   (WPCF MOP No. 17), Paints and Protective Coatings for Wastewater Treatment Facilities.

3. WPCF Manual of Practice No. 11, Chapter 8
   Operation of Wastewater Treatment Plants, Sludge Conditioning.

Glossary of Terms and Sample Calculations

1. Solids content, also called percent total solids, is the weight of total solids in sludge per unit total weight of sludge, expressed in percent. Water content plus solids content equals 100 percent.

2. **Solids loading** is the feed solids to the belt filter on a dry weight basis including chemicals per unit time.

3. **Filtrate** is the effluent or liquid portion of a sludge removed by or discharged from a filter.

XII

SLUDGE DRYING BEDS

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PROCESS DESCRIPTION

Drying beds are generally used for dewatering of well digested sludges. Attempts to air dry raw sludge usually results in odor problems.

general construction

Sludge drying beds consist of perforated or open joint drainage pipe laid within a gravel base. The gravel is covered with a layer of sand. Partitions around and between the drying beds may be of concrete, wood or earthen embankment. Drying beds are generally open to the weather but may be covered with ventilated green-house type of enclosures where it is necessary to dewater sludge in wet climates.

drying operation

The drying of sludge on sand beds is accomplished by allowing water to drain from the sludge mass through the supporting sand to the drainage piping and natural evaporation to the air. As the sludge dries, cracks develop in the surface allowing exaporation to occur from the lower layers which accelerates the drying process.

Typical sludge drying bed construction is shown in Figure XII-1 (see following page).

construction variations

Many design variations are used for sludge drying beds including the layout of the drainage piping, thickness and type of materials in the gravel and sand layers, and construction materials used for the partitions. The major variation is whether or not the beds are covered. Any covering structure must be well ventilated. In the past, some beds were constructed with flat concrete bottoms for drainage without pipes, but this construction has not been very satisfactory.

sidestream

The only sidestream is the drainage water. This water is normally returned to the raw sewage flow to the plant or to the plant headworks. The drainage water is not normally treated prior to return to the plant.

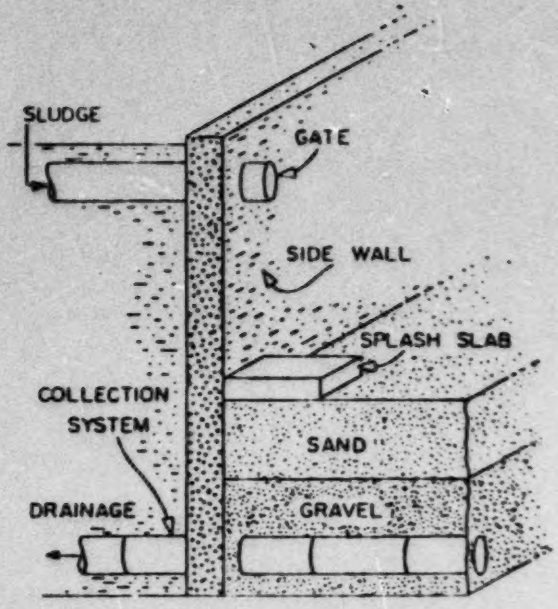
SLUDGE
GATE
SIDE WALL
SPLASH SLAB
COLLECTION SYSTEM
SAND
DRAINAGE
GRAVEL

Figure XII-1. Typical sludge drying bed construction.

TYPICAL DESIGN CRITERIA & PERFORMANCE

The following data was developed from "Process Design Manual for Sludge Treatment and Disposal", (EPA 625/1-74-006) and "WPCF Manual of Practice No. 20".

Design	Typical design values
Gravel layer depth, inches, typically 3-inch layers graded from coarse at bottom to fine at top	12-18
Sand layer depth, inches, typically 0.55 mm size	6-12
Drainage pipe spacing, feet (typically 6-inch diameter)	8-20
Sludge depth, inches	8-12
Typical module size, feet:	
Length	20-100
Width	20-25

	open beds	covered beds
Bed sizing, sq ft/capita, from WPCF, 1959:		
Primary digested sludge	1.0 - 1.5	0.75 - 1.0
Primary and humus digested sludge	1.25 - 1.75	1.0 - 1.25
Primary and activated digested sludge	1.75 - 2.5	1.25 - 1.5
Primary and chemically precipitated digested sludge	2.0 - 2.5	1.25 - 1.5
Performance		
Solids Loading Rate, lb/yr/sq ft	up to 25	up to 40
Moisture Content of Dried Sludge, percent	50 - 60	50 - 60

Sidestream

The flow from the drainage piping consists primarily of the initial percolation of water from the sludge plus some periodic percolation after rain storms (assuming open beds).

Percolation from initial drainage of sludge assuming a 10-inch layer of 5 percent solids sludge and initial drainage to 18 percent solids will be:

$$10 \text{ inches} - \frac{0.05}{0.18}(10) = 7.2 \text{ inches water}$$

OR

4.5 gal/sq ft of bed area drainage over the first 2 or 3 days

Drainage water BOD_5 = 200 to 400 mg/l

Suspended solids = 50 to 100 mg/l

STAFFING REQUIREMENTS

Labor requirements shown in Table XII-1 include removal of dried sludge from beds, sand maintenance, and weeding as necessary.

TABLE XII-1. SLUDGE DRYING BEDS, LABOR REQUIREMENTS

Total bed area, sq ft(*)	Labor, hr/yr		
	Operation	Maintenance	Total
1,000	300	100	400
5,000	400	180	580
10,000	500	220	720
50,000	1,500	710	2,210
100,000	2,900	1,500	4,400

(*) Assuming dry solids loading rate of 20 lb/yr/sq ft of bed area.

NORMAL OPERATING PROCEDURES

Initial Inspection

1. All lines should be clear of debris and valves checked for free operation.
2. The sand surface should be level and all irregularities raked smooth.

3. Clear all debris from surface of bed.

4. Install stoplogs or other blocking device at vehicle entrance to drying bed (if provided).

5. Make sure a splash plate or other diffusion device is in place where the sludge enters the bed.

6. Check drainage return system and piping.

Startup

1. Start flow of liquid sludge into bed. Stop flow when the liquid is approximately 8 to 12 inches deep throughout the bed.

2. If bed is enclosed, open the ventilation openings.

3. Do not apply new sludge on top of a layer of dry sludge.

Routine Operations

1. Inspect the beds every few days noting any odors or insect problems.

2. Remove any weed growth.

3. When sludge is dry (normally 3 weeks or longer depending on weather and depth of sludge) remove the sludge taking care not to damage the sand and gravel layers. Remove as little sand with the sludge as possible.

4. Vehicles and equipment should not be operated directly on the sand but should be operated on planks or plywood laid on top of the bed if permanent vehicle treadways are not provided.

5. After the sludge is removed, inspect the bed, rake the surface of the sand to level it and to remove any debris, and add makeup sand if necessary.

6. The bed is ready for the next application of sludge.

CONTROL CONSIDERATIONS

Physical Control (Instrumentation)

Instrumentation is normally not provided for drying beds except in some cases sludge and drainage flow rates may be measured.

Process Control

application to bed

Experience is the best guide in determining the depth of sludge to be applied, however typical application depth is 8 to 12 inches. The condition and moisture content of the sludge, the sand bed area available, and the need to draw sludge from digesters are factors to consider. Do not apply fresh sludge on top of dried sludge in a bed.

drying

A thinner layer will dry more rapidly permitting quick removal and reuse of the bed. An 8-inch layer should dry in about 3 weeks in the open during reasonably dry weather. A 10-inch layer of the same sludge will take 4 weeks so that the 25 percent additional sludge actually takes 30 percent more time to dry. In some cases it may be desirable to apply sludge in a layer thinner than 8 inches. The best operation can only be determined by trial and error and may also vary seasonally.

removal

The best time to remove dried sludge from drying beds depends on a number of factors such as subsequent treatment by grinding or shredding, the availability of drying bed area for application of current sludge production, labor availability, and, of course, the desired moisture content of the dried sludge. Sludge can be removed by shovel or forks at a moisture content of 60 percent, but if it is allowed to dry to 40 percent moisture, it will weigh only half as much and is still easy to handle. If the sludge gets too dry (10 to 20 percent moisture) it will be dusty and will be difficult to remove because it will crumble as it is removed. Many operators of smaller treatment plants use wheelbarrows to haul sludge from drying beds. Planks are often laid on the bed for a runway so that the wheelbarrow tire does not sink into the sand. Wheelbarrows can be kept close to the worker so that the shoveling distance is not great. Most plants use pickup trucks or dump trucks to transport the sludge from the drying bed. Dump trucks have the advantage of quick unloading and most municipalities have dump trucks available. Where trucks are used, it is best to install concrete treadways in the sludge drying bed wide enough to carry the dual wheels since the drying bed can be damaged if the trucks are driven directly on the sand. The treadways should be installed so that good access is provided to all parts of the beds. If permanent treadways have not been installed, heavy planks may be placed on the sand. Large plants will normally utilize mechanical equipment for handling the dried sludge. Some communities have encouraged public usage of the dried sludge. In some cases users are allowed to remove the sludge from the beds, but this may not be satisfactory in many cases. Local regulations should be reviewed before attempting to establish a public utilization program.

odors

Two basic approaches are available to control or counteract odors: chemicals sprayed into the atmosphere or chemicals added to the sludge as it is being placed on the beds. Chemicals are available which may be sprayed into the atmosphere in the vicinity of the odor to counteract or mask the odor. Such chemicals are described in the February, 1977 issue of Water and Wastes Engineering magazine. Odors may also be controlled effectively by adding chloride of lime to the sludge as it is discharged to the drying beds. Hydrated lime sometimes is used for odor control, but tends to clog the sand. These chemicals can be obtained from industrial chemical suppliers.

flies

Flies may be a problem in certain areas and seasons and should be controlled by destruction of breeding and use of traps and poisons. The fly may be controlled most effectively in the larva stage and borax or calcium borate will kill the larvae. Neither chemical is dangerous to man nor to domestic animals. These chemicals can be sprinkled on the sludge, especially in the cracks of the drying cake. Other chemicals sometimes used are chloride of lime and sulfate of iron. The adult fly can be killed by spraying. Fly trapping is particularly suited for outdoor conditions. A satisfactory form of trap consists of a conical, gauze-covered structure leading into a larger space in which a sugary, poisoned bait is placed.

EMERGENCY OPERATING PROCEDURES

The only emergency that would affect the operation of the drying beds is the loss of the sludge digestion process. Undigested or poorly digested sludge applied to drying beds is likely to result in odor problems and should not be attempted.

COMMON DESIGN SHORTCOMINGS

Shortcomings	Solution
1. Inadequate drying bed capacity.	1a. This is a common problem and typical design criteria are inadequate for many areas.
	1b. Construct more beds.
	1c. Try to apply drier sludge to beds.
	1d. Remove sludge as soon as it is dry or remove it in a wetter state.

Shortcomings	Solution
2. Poor or no drainage system.	2a. Best solution is to add a drainage system as this type of drying bed is rarely satisfactory for the intended purpose.
3. Inadequate access for removal of dried sludge.	3a. Cut an opening for vehicle access into one wall of bed.
	3b. Cast concrete treadways within drying bed supported from bottom of bed and extending to surface of sand.
	3c. Use planks and plywood laid on top of beds for access.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Odors from drying beds.	1. Incomplete digestion of sludge.	1. Digestion process.	1a. Provide complete digestion. 1b. Feed chemicals to sludge as it is applied to bed.
2. Sludge will not dry (in good weather).	2a. Poor drainage.	2a. Drainage piping for plugging.	2a. Completely clean and rake surface of bed before applying new sludge.
	2b. Too much sludge applied to bed.	2b. Sand and gravel for plugging.	2b. Repair drainage piping. 2c. Replace sand and gravel if necessary. 2d. Reduce depth of sludge applied to bed. 2e. Add 1 pound of alum per 100 gallons of sludge as the sludge is applied to the bed.
3. Sludge is dusty and crumbles.	3. Excessive drying.	3. Moisture content.	3. Remove sludge from bed when it dries to 40 to 60 percent moisture content.

MAINTENANCE CONSIDERATIONS

bed surface

Some sand is removed during each sludge removal cycle. The amount depends on the method of removing the dried sludge. The sand depth should be checked periodically from an established reference point such as the top of the bed wall until a pattern is established. Sand should be added when the depth has decreased to 3 or 4 inches. The surface of the sand should be levelled and raked prior to each sludge application.

weeding

Plants such as tomatoes and weeds may sprout and grow in the drying sludge. These growths should be controlled either by spraying with weed killer or hand pulling.

drainage

The drainage system should be inspected and maintained so that free drainage takes place from the drying beds. It can be inspected for proper operation shortly after new sludge is placed in a bed.

sludge lines

Sludge lines and valves should be regularly inspected and maintained as leaky valves may allow wet sludge to enter a bed during the drying process. Sludge lines must be drained after use in winter to prevent freezing.

partitions

The partitions between and around the beds should be tight so that sludge will not flow from one compartment to another nor outside the beds. If earth beds are used, grass and other vegetation should be kept cut. Stop logs or other provisions for closing vehicular access cutouts in drying bed walls should be kept well maintained to minimize leakage.

SAFETY CONSIDERATIONS

Since anaerobic digestion of sewage sludge produces combustible gases, smoking or open fires should be prohibited when discharging anaerobically digested sludge to the drying beds.

REFERENCE MATERIAL

References

1. WPCF Manual of Practice No. 11, Chapter 9, Operation of Wastewater Treatment Plants, Sludge Dewatering.

2. WPCF Manual of Practice No. 20, Chapter 3, Sludge Dewatering, Land Method.

Glossary of Terms and Sample Calculations

1. **Solids loading rate** is the weight of solids on a dry weight basis applied annually per square foot of drying bed area. As an example, assume that 10 inches of 5 percent solids anaerobically digested sludge is applied to a drying bed five times per year. The weight of solids will be calculated for one square foot of bed.

   Solids Loading Rate =

   $$\left(\frac{\text{dry weight of solids}}{\text{year}}\right) \div \left(\frac{\text{square feet of}}{\text{drying bed}}\right)$$

   $$= \left(\frac{\text{cubic feet of sludge}}{\text{square feed of bed}}\right)\left(\frac{\text{lbs}}{\text{ft}^3}\right)\left(\frac{\text{\% solids}}{100}\right)\left(\text{Number of applications}\right)$$

   $$= \left(\frac{1 \times 1 \times \frac{10}{12}}{\text{sq ft of bed}}\right)\left(\frac{62.4\ \text{lbs}}{\text{ft}^3}\right)\left(\frac{5}{100}\right)\ (5)$$

   $$= 13\ \frac{\text{lbs}}{\text{year-sq ft}}$$

2. **Sludge moisture content** is the weight of water in a sludge sample divided by the total weight of the sample. This is normally determined by drying a sludge sample and weighing the remaining solids. Total weight of the sludge sample equals the weight of water plus the weight of the dry solids. As an example, assume that 100 grams of sludge is evaporated and produces 5 grams of residue.

   $$\text{solids content} = \frac{5}{100} \times 100 = 5\%$$

   $$\text{moisture content} = \frac{(100-5)}{100} \times 100 = 95\%$$

3. **BOD_5** (biochemical oxygen demand) is the amount of oxygen required for the biological oxidation of degradable organic content in a liquid, in a specific time, and at a specified temperature. Results of the standard test assessing wastewater strength usually are expressed in mg/l as 5-day 20°C BOD (BOD_5).

4. **Suspended solids** are solids that either float on the surface of, or are in suspension in, water, wastewater, or other liquids, and which are largely removed by laboratory filtering.

5. mg/l is an expression of the weight of one substance within another. Commonly it is used to express weight of a substance within a given weight of water and wastewater. It is sometimes expressed as parts per million (ppm) which is equal to mg/l. If there is one pound of a substance mixed in one million pounds of water the resulting concentration is one mg/l.

$$\text{concentration, mg/l} = \frac{\begin{array}{c}\text{weight of carrying substance} \\ \text{(water or wastewater)}\end{array}}{\text{weight of substance x } 10^6}$$

XIII

LAGOONS

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PROCESS DESCRIPTION

Sludge lagoons are similar to sand beds in that sludge is periodically drawn from a digester, placed in the lagoon, removed after a period of drying, and the cycle repeated. Drying lagoons are not typically provided with an underdrain system as most of the drying is accomplished by decanting supernatant liquor and by evaporation. Plastic or rubber fabrics may be used as a bottom lining, or they may be natural earth basins. Supernatant liquor and rainwater drain off points are usually provided with the drain off liquid returned to the plant for further processing.

TYPICAL DESIGN CRITERIA & PERFORMANCE

Design parameter	Range
Solids loading rate	2.2 - 2.4 lb/yr/cu ft of lagoon capacity
Area required:	
Examples:	
Dry climate, primary sludge	1 sq ft/capita
Wet climate, activated sludge	3-4 sq ft/capita
Dike height	2 ft
Sludge depth after decanting (depths of 2-4 ft have been used in very warm climates)	15 in
Drying time for depth of 15 in or less	3 - 5 mon

STAFFING REQUIREMENTS

Labor requirements shown in Table XIII-1 (see following page) include application of sludge to the lagoon, periodic removal of solids and minor maintenance requirements such as dike repair.

TABLE XIII-1. SLUDGE LAGOON LABOR REQUIREMENTS

Dry solids applied, tons/year	Labor, hr/yr Operation	Maintenance	Total
100	30	55	85
1,000	55	90	145
10,000	120	300	420
50,000	450	1,500	1,950

MONITORING

Monitoring of sludge lagoons generally consists of sensory observations and interpretations by the plant operator. However, records may be kept on the sludge loading, quantity, depth, date, drying time and weather conditions. This will provide the operator with the information necessary to determine the optimal time of sludge removal from the lagoon by correlating sludge moisture content with time of drying for particular climatic conditions.

CONTROL CONSIDERATIONS

weeds

Weeds and other vegetation should always be removed from the lagoon area before filling with sludge.

sludge depth

Sludge depth should not exceed 15 inches after excess supernatant has been drawn off. Unless the lagoon is situated in an arid climate, depths of over 15 inches will require excessive drying time.

dewatering

Sludge will generally not dewater in any reasonable period of time to the point that it can be lifted by a fork except in an extremely hot, arid climate. If sludge is placed in depths of 15 inches or less, it may, typically, be removed with a front-end loader in 3 to 5 months. When sludge is to be used for soil conditioning, it may be desirable to stockpile it for added drying before use. One approach utilizes a 3-year cycle in which the lagoon is loaded for 1 year, dries for 18 months, is cleaned, and allowed to rest for 6 months.

drying rate

There are few operational variables under the control of the operator other than pretreatment and thickening of sludge prior to discharge to the lagoon. Once discharged to the lagoon, the drying rate is largely dependent upon weather conditions.

supernatant removal

The operator should promptly remove supernatant liquor and rainwater so that the sludge cake is exposed to oxygen in the air and can dry rapidly. Supernatant is normally returned to the main plant treatment processes.

EMERGENCY OPERATING PROCEDURES

The only emergency that may directly affect the operation of the sludge lagoon is the loss of the sludge digestion process. Undigested or poorly digested sludge applied to lagoons is likely to result in an odor problem and should be avoided.

COMMON DESIGN SHORTCOMINGS

Adverse weather conditions may prolong drying of sludge, however, short rainy periods followed by sunny conditions should pose no problems. Problems of too little lagoon area may be minimized by always removing the sludge when it is dry enough and removing supernatant as it forms.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Odors from lagoons.	1a. Inadequately digested sludge.	1a. Operation of digestion process.	1a. Establish correct digester operation (see appropriate section of manual); apply lime to surface of lagoon.
	1b. Excess water in lagoon.		1b. Decant supernatant and rainwater promptly.
2. Insect breeding problems in lagoons.	2. Excess water in lagoon.		2. Decant supernatant and rainwate promptly; apply insecticides.
3. Supernatant decanted from lagoon is upsetting treatment process when recycled.	3a. Broken dikes between lagoons causing freshly drawn sludge to enter supernatant.	3a. Dike condition.	3a. Repair broken dikes.
	3b. Supernatant being drawn prematurely.	3b. Suspended solids of supernatant.	3b. Delay drawing of supernatant until sludge has settled.
	3c. Excessive sludge depths applied causing supernatant drawoff to be below sludge interface.	3c. Sludge application depths.	3c. Apply shallower sludge depths.

MAINTENANCE CONSIDERATIONS

Maintenance requirements are very low for sludge lagoons. Repairing of broken dikes and decanting of excess water from rain or snow require minimal operator time. If odor and fly control become a problem, see the section on maintenance in the SLUDGE DRYING BED manual for solutions.

SAFETY CONSIDERATIONS

Since anaerobic digestion of sewage sludge produces combustible gases, smoking or open fires should be prohibited when discharging anaerobically digested sludge to the lagoon. Fencing of lagoons may be desirable to prevent trespassing.

REFERENCE MATERIAL

References

1. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, 1015 Eighteenth Street, N.W., Washington, D.C. 20036.

2. WPCF Manual of Practice No. 20, Chapter 3, Sludge Dewatering.

XIV

HEAT DRYING

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PROCESS DESCRIPTION

process

Heat drying raises the temperature of the incoming sludge to 212°F (100°C) to remove moisture which reduces total volume, yet retains the nutrient properties of the sludge. The end product is odor free, contains no pathogenic organisms, and contains soil nutrients.

types

Sludge has been heat dried in flash drying equipment and rotary kilns as shown in Figures XIV-1 and XIV-2 (see following pages) respectively.

flash drying

Before introduction into the flash dryer, the sludge must undergo thickening and dewatering. The degree of dewatering depends on the dewatering process used. The incoming dewatered sludge is blended with a portion of the previously heat dried sludge in a mixer. Hot gases from the furnace at approximately 1,200° to 1,300°F (650° to 700°C) then are mixed with the blended sludge before drying in the cage mill. Agitation in the cage mill dries the sludge to approximately 2 to 10 percent moisture and reduces the temperature to approximately 300°F (150°C) before cyclone separation of the solids from the gases. A portion of the dried solids are recycled to the cage mill and the rest are stored for use or incinerated. The gases from the cyclone separators are conveyed by the vapor fan to the deodorization preheater in the furnace where the temperature is raised to approximately 1,200° to 1,400°F (650° to 760°C). The deodorized gases release a portion of the heat to the incoming gases and release more heat in the combustion air preheater. The temperature is reduced to approximately 500°F (260°C) before the gas is scrubbed for particulate removal and conveyed to the stack by the induced draft fan. If the dried solids are not used in the furnace as a fuel, then auxiliary fuel such as gas, oil, or coal is necessary.

rotary kiln

The rotary kiln is a cylindrical steel shell mounted with its axis at a slight slope from the horizontal. Dewatered sludge is fed continuously into the upper end. A portion of the dried sludge is mixed with the feed sludge to reduce moisture and disperse the cake. These vanes pick up the material, then steadily spill it off in the form of a thin sheet of falling particles as the dryer rotates. This action is intended to provide contact between sludge and gases to promote rapid drying. The dried sludge from such

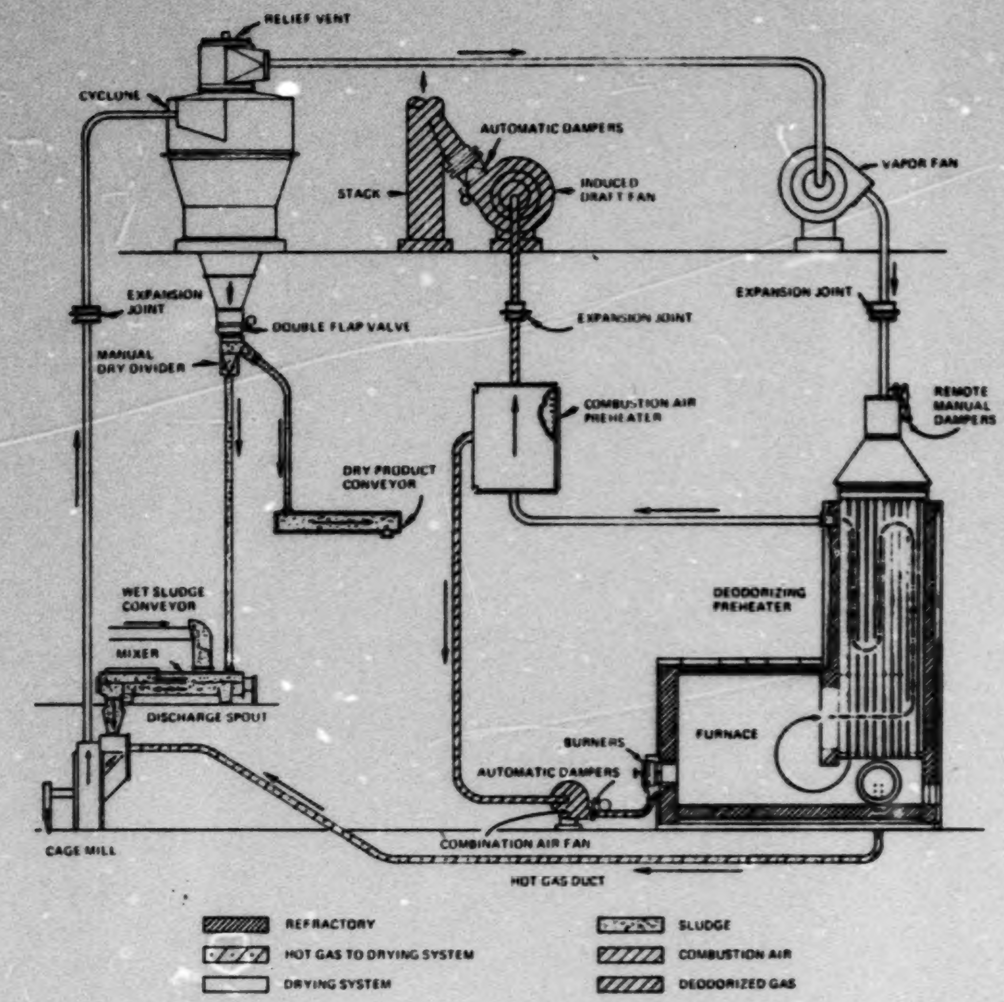

RELIEF VENT
CYCLONE
AUTOMATIC DAMPERS
STACK
INDUCED DRAFT FAN
VAPOR FAN
EXPANSION JOINT
DOUBLE FLAP VALVE
MANUAL DRY DIVIDER
EXPANSION JOINT
EXPANSION JOINT
COMBUSTION AIR PREHEATER
REMOTE MANUAL DAMPERS
DRY PRODUCT CONVEYOR
DEODORIZING PREHEATER
WET SLUDGE CONVEYOR
MIXER
DISCHARGE SPOUT
FURNACE
BURNERS
AUTOMATIC DAMPERS
CAGE MILL
COMBINATION AIR FAN
HOT GAS DUCT
REFRACTORY
HOT GAS TO DRYING SYSTEM
DRYING SYSTEM
SLUDGE
COMBUSTION AIR
DEODORIZED GAS

Figure XIV-1. Flash dryer system.

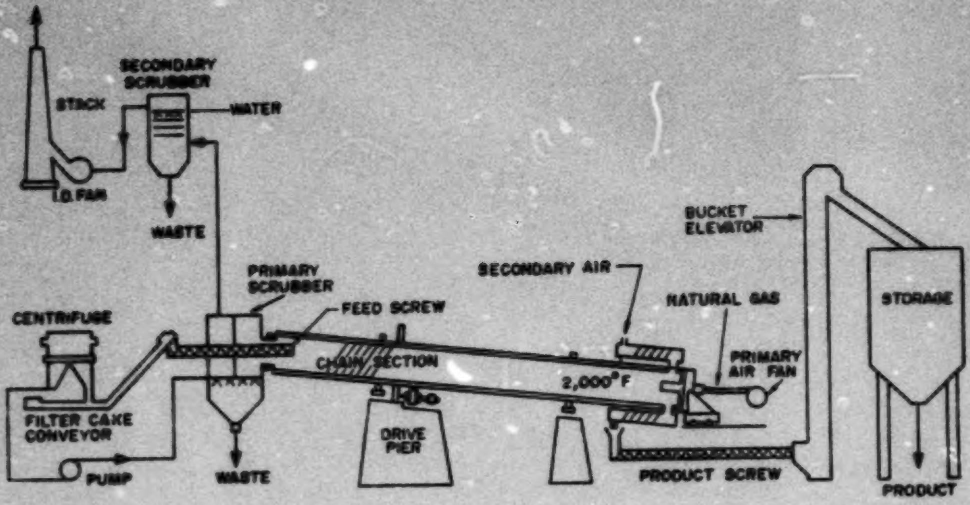

STACK
SECONDARY SCRUBBER
WATER
I.D. FAN
WASTE
PRIMARY SCRUBBER
FEED SCREW
CENTRIFUGE
CHAIN SECTION
SECONDARY AIR
NATURAL GAS
BUCKET ELEVATOR
STORAGE
PRIMARY AIR FAN
2,000°F
FILTER CAKE CONVEYOR
DRIVE PIER
PUMP
WASTE
PRODUCT SCREW
PRODUCT

Figure XIV-2. Rotary kiln dryer.

a unit will consist of varied sizes of particles that may require grinding before use. Deodorization of the exhaust gases by afterburning at approximately 1,200° to 1,400°F (650° to 760°C) is necessary if odors are to be avoided. Also, scrubbers must be used to remove particulates from the exhaust gases.

differences

Generally, the normal operating conditions of the flash dryer are applicable to the rotary dryer. The differences arise in that the rotary dryer is direct fired, the temperature around the cake being controlled at approximately 700°F (370°C). The dryer rotates at approximately 4 to 8 percent per minute to ensure mixing as opposed to the rapid mixing provided in the cage mill on a flash dryer.

TYPICAL DESIGN CRITERIA AND PERFORMANCE

Flash dryers and rotary kilns are sized on the basis of the solids loading rate and heating requirements. The principles that apply are similar to those used in designing sludge incinerators. Flash dryers and rotary kilns are usually available in several module sizes with sludge burning capacities typically ranging from 40 pounds per hour to 2,400 pounds per hour of sludge feed.

The expected performance from a flash dryer or rotary kiln is a dried sludge with a moisture content ranging from 2 to 10 percent.

Heat drying in general, produces an exhaust that contains unacceptable quantities of air pollutants. Therefore, the system design usually includes equipment necessary to reduce the emissions to acceptable levels. This may require particulate collection efficiencies as high as 96 to 97 percent.

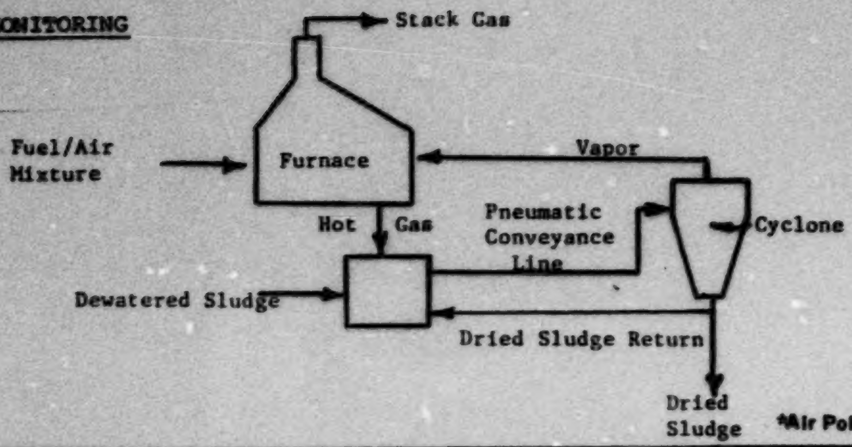
STAFFING REQUIREMENTS

Labor requirements for operation and maintenance of heat drying systems include sludge conveyors, control center and the enclosing structure. The requirements are based on tons of dry solids processed per year and are shown in Table XIV-1.

TABLE XIV-1. HEAT DRYING OF SLUDGE LABOR REQUIREMENTS

Dry solids processed, tons/year	Labor, hr/yr		
	Operation	Maintenance	Total
50	500	120	620
100	750	180	930
500	1,300	300	1,600
1,000	2,080	441	2,520
5,000	3,000	600	3,600
10,000	5,200	1,040	6,240

MONITORING


Stack Gas
Fuel/Air Mixture
Furnace
Vapor
Hot Gas
Pneumatic Conveyance Line
Cyclone
Dewatered Sludge
Dried Sludge Return
Dried Sludge

*Air Pollution Control District

		Sample Frequency	Sample Location	Sample Method	Reason for Sample
Suggested Minimum	Percent Solids	1/day	Dewatered Sludge Dried Sludge	Grab	Process Control
	Temperature	Continuous	Furnace, Stack gas, dewatered and dried sludge	Record Continuously	Process Control
	Sludge Feed Rate	Continuous	Dewatered Sludge	Record Continuously	Process Control
	Oxygen	Continuous	Stack Gas	Record Continuously	Furnace Control
	Particulates	As required by APCD*	Stack Gas	Record or Grab	Air Pollution Control
	SO_2, NO_x, CO, CO_2	As required by APCD*	Stack Gas	Record or Grab	Air Pollution Control
	Fuel Consumption	Continuous	Furnace Input	Record Continuously	Furnace Control
	Air Flow	Continuous	Furnace Input	Record Continuously	Furnace Control
Optional	Ash Content	1/month	Dried Sludge	Grab	Determine characteristics prior to use or disposal.
	Nutrient Content	1/month	Dried Sludge	Grab	
	Density	1/month	Dried Sludge	Grab	
	Toxicity	1/month	Dried Sludge	Grab	

NORMAL OPERATING PROCEDURES

Startup

Normal operation of heat drying equipment varies from one installation to another. Large installations may operate continuously while smaller facilities may operate one 8-hour shift per day or less. With operation that is less than continuous a warmup period of one hour or so is necessary to allow the system to reach operating temperatures before drying begins.

1. After initial settings and inspection, ignite furnace burner.
2. Adjust fuel and air flows, damper and other control to obtain desired flame.
3. Start exhaust fans and cooling fans if necessary.
4. Allow sufficient warmup period for system to reach operating temperatures.
5. Turn on mixer, cage mill, and conveyor.
6. Start sludge feed.

Routine Operations

1. Inspect system periodically during shift.
2. Check system temperature, pressure, fuel flow, air flow, etc., to insure safe and proper operation.
3. Carry out maintenance required including clean up and washdown of conveyors and wet sludge handling equipment.
4. Take samples as outlined in MONITORING section.

Shutdown

1. Shutdown sludge feed and conveyors.
2. Turn off mixer and cage mill.
3. Shutdown furnace.
4. Adhere to manufacturer's recommendations for cooling of furnace with blowers. This will minimize the possibility of damage to the equipment.

5. If shutdown is only for a few hours it may be more practical and more economical to reduce the furnace flame, i.e., idle the system. This will minimize warmup time when operation is resumed.

CONTROL CONSIDERATIONS

Physical Control

Typically, the flow through the heat drying equipment should be set for as constant a rate as possible. This will result in the most efficient operation.

pollution equipment

Normally, the exhaust gases from heat drying equipment are afterburned to prevent odors and scrubbed to remove particulates. Several types of equipment are used for this operation. The operator should familiarize himself with the operation of the particular equipment at his plant to insure compliance with local air pollution codes.

sludge caking

Some of the heat drying equipment such as pneumatic conveyors may be subject to caking or blockage if the mixture of the cake and dried sludge becomes too wet. If this occurs, adjust flow to provide a drier mixture.

temperature

A horn alarm should sound if unsuitable temperature conditions exist. In this case, the operator should determine the cause immediately and correct the situation or shutdown the operation.

Process Control

Efficient and consistent operation of heat drying equipment depends on frequent monitoring, both sensory and analytical.

inspection

The drying equipment should be inspected periodically during the shift. The sludge should be dried to the desired percent moisture and be free of odors. Operating temperatures, pressures, flow rates, etc., should be noted to detect any irregularities. After gaining some operating experience it should also be possible to recognize any strange sounds or changes in pitch that may indicate a problem.

sampling

Sampling should be performed as outlined under MONITORING. Provisions should be made for grab sampling to minimize any safety hazard from hot piping or equipment.

analysis

Samples should be analyzed according to procedures specified in Standard Methods.

The following major variables affect the operation of the heat drying equipment and are discussed in this section.

1. Percent solids in wet sludge feed
2. Ratio of dried sludge/wet sludge mixture
3. Quantity of hot combustion gases used for drying
4. System temperatures

solids

To produce a product at the desired moisture content ranging from 2 to 10 percent, control must be exercised on the sludge dewatering process preceding the heat drying equipment. Efficient operation depends on a consistent percent solids concentration in the sludge feed. The percent solids in the feed is also critical to the economy of operation of heat dryers. The higher the moisture content of the incoming sludge the more fuel that must be burned to evaporate the added moisture.

dried sludge to wet sludge ratio

As shown in Figures XIV-1 and XIV-2 the incoming sludge is mixed with previously dried sludge to create the proper consistency for pneumatic conveying equipment. A significant change in the incoming percent solids concentration will change the ratio required for proper operation. This ratio is variable depending on the sludge used and the incoming percent solids. It must be determined through actual trial and error.

hot combustion gas

For efficient operation the quantity of hot combustion gases used for drying should be just enough to dry the cake to the desired percent solids. This depends on the ratio of the dried to wet sludge mixture and the sludge flow rate. This should be determined through operational experience.

system temperatures

System operating temperatures should be maintained as suggested in the manufacturer's manuals. Operating temperatures that are too low will not properly dry the sludge mixture. High operating temperatures are inefficient and costly.

EMERGENCY OPERATING PROCEDURES

Loss of Power

Power interruptions will affect the heat drying process since electrical equipment will not operate. Without conveyors, fans and blowers the process will not convey sludge mixtures through the system. The manufacturer's manual for the furnace equipment must be checked to determine if overheating will result with no cooling fans operable. If this is not a problem, it may be possible to "idle" the furnace by turning the flame down until power is regained and the process resumed.

Loss of Other Treatment Units

The loss of the sludge dewatering process prior to the heat drying operation will greatly affect the economics of the heat drying equipment, if sludge with a higher than usual moisture content is fed to the system. In this case it may be desirable to store the sludge until the dewatering process is regained. In case of a prolonged problem it may be necessary to haul sludge to another treatment facility or disposal.

COMMON DESIGN SHORTCOMINGS

Shortcoming	Solution
1. "Clinkers" or clumps develop in the dried sludge.	1. Install grinding equipment to pulverize sludge before final use. This is a common problem of rotary kiln heat dryers.
2. Mixers, air locks, cage mills, dryers, metal equipment subject to excessive wear and corrosion.	2. This is a common problem due to the corrosive nature of the dried sludge. Set up frequent, periodic maintenance schedule on parts, including coating of metal surfaces where applicable.
3. Serious air pollution such as particulates and odor from stack gas.	3. Install afterburner and scrubbers as suggested or required by air pollution control departments.

Shortcoming	Solution
4. Stockpiling of dried sludge at 2 to 10 percent moisture susceptible to spontaneous combustion fires.	4. Find a market or outlet for dried sludge so stockpiling is minimized, or unnecessary.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Sludge not properly dried.	1a. Furnace temperature too low.	1a. Furnace temperature.	1a. Increase temperature as required.
	1b. Ratio of wet to dried sludge too high.	1b. Moisture content of wet/dry sludge mixture.	1b. Change ratio to provide drier mixture.
	1c. Quantity of hot combustion gases sent to dryer too low.	1c. Hot gas flow.	1c. Increase flow of combustion gases.
	1d. Moisture content of feed sludge too high.	1d. Percent solids of feed sludge.	1d. Check operation of dewatering equipment preceding heat drying equipment. Increase percent solids output.
2. Decreased sludge flow in pneumatic lines.	2a. Caking or blockage of line with wet mixture of sludge.	2a. Moisture content of wet/dry sludge mixture.	2a. Change ratio to provide drier mixture.
3. Decreased flow in fans & ductwork.	3a. Grease accumulation.	3a. Visually inspect ducting, fans.	3a. Steam clean equipment as required.
4. Excessive particulates in stack gas.	4a. Faulty or poorly operating pollution control equipment.	4a. Pollution control equipment.	4a. Correct operation of pollution control equipment - see manufacturer's manual.
5. Excessive odors in stack gas.	5a. Temperature of afterburner too low.	5a. Afterburner temperature.	5a. Operate after burner between 1,200-1,400°F (650-700°C)

MAINTENANCE CONSIDERATIONS

A good preventive maintenance program will reduce breakdowns which could be not only costly, but also very unpleasant for operating personnel. All maintenance should be geared to provide smooth operation and prevent potential total outages or disasters. Plant components including the following should be inspected periodically for wear, corrosion, and proper adjustment:

mechanical

1. Drives and gear reducers
2. Sludge belt conveyors
3. Pneumatic conveyor system
4. Bearing brackets
5. Mixers and cage mills
6. Electrical contacts in starters and relays
7. Burners
8. Furnace and related equipment

heat exchangers

Cleaning of heat exchangers and other components should be done on a regular bases as determined necessary through operational experience or as recommended by the manufacturer. Items that have a predictable service life as determined through operation, should be replaced on a uniform basis. If shutdown is required to replace these items, this is a good time to inspect the entire system.

SAFETY CONSIDERATIONS

The complex mechanical equipment and extremely high temperatures associated with the heat drying equipment require a conscientious safety effort. Hazardous areas should be marked with warning signs including cautions against contact with hot surfaces. Any equipment that creates a hazard upon a malfunction should be equipped with sensors and data recorded to evaluate operating conditions and signal any breakdowns.

General safety considerations also apply. At least two persons should be present when working in enclosed tanks or in elevated areas not protected by handrails. Walkways and work areas should be kept free of grease, oil, leaves and snow. Protective guards and covers must be in place unless mechanical/electrical equipment is locked out of operation.

REFERENCE MATERIAL

References

1. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, 1015 Eighteenth Street, N.W., Washington, D.C. 20036.

2. WPCF Manual of Practice No. 17 (WPCF MOP No. 17), Paints and Protective Coatings for Wastewater Treatment Facilities.

3. WPCF Manual of Practice No. 11, Chapter 22, Operation of Wastewater Treatment Plants, Heat Drying.

Glossary of Terms and Calculations

1. Caking is the blocking of pneumatic conveying equipment or other equipment by sludge that is enough to form a plug or mud ball in the line.

2. Pneumatic Conveyor is a system that uses air pressure to move the sludge mixture through pipes from one piece of equipment to the next.

3. Solids Concentration is the weight of the solids per unit weight of the sludge. It can be calculated in percent as follows:

$$\text{concentration} = \frac{\text{weight of dry sludge solids}}{\text{weight of wet sludge}} \times 100$$

4. Solids Loading is the feed solids applied in pounds per hour.

XV

MULTIPLE HEARTH INCINERATION

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PROCESS DESCRIPTION

process design

A multiple hearth furnace consists of a circular steel shell surrounding a number of solid refractory hearths and a central rotating shaft to which rabble arms are attached. The operating capacity of these furnaces is related to the total area of the enclosed hearths. They are available in diameters ranging from 4.5 feet to over 22 feet and with four to twelve hearths as shown in Table XV-1 (see following page). Capacities of multiple hearth furnaces vary from 200 to 8,000 pounds per hour of dry sludge with operating temperatures of 1,400 to 1,700°F. The dewatered sludge enters at the top through a flapgate and proceeds downward through the furnace from hearth to hearth moved by the rotary action of the rabble arms. The hearths are constructed of high heat duty fire brick and special fire brick shapes.

mechanical features

Two doors are typically provided in the wall of each hearth. They are fitted to cast iron frames and have machined faces to provide reasonably tight closures. An observation port with closure is provided in each door. Since the furnace may operate at temperatures up to 2,000°F, the central shaft and rabble arms are effectively cooled by air supplied from a blower which discharges into a housing at the bottom of the shaft. The shaft is motor driven and the rotational speed is adjustable from about one-half to one and one-half revolutions per minute. Two or more rabble arms are connected to the shaft at each hearth. Each rabble arm is constructed with two internal air passages. One passage conducts air from the cold air tube of the central shaft to the end of the rabble arm and the other returns this air back to the hot air tube of the central shaft. The air may be discharged to atmosphere or returned to the bottom hearth of the furnace as preheated air for combustion purposes.

operation

The rabble arms provide mixing action as well as rotary and downward movement of the sludge. The flow of combustion air is countercurrent to that of the sludge. Gas or oil burners are provided on some of the hearths for furnishing heat for start-up or supplemental use as required. Sludge is constantly turned and broken into smaller particles by the rotating rabble arms which exposes the sludge surface to hot furnace gases. This facilitates rapid and complete drying as well as burning of sludge.

TABLE XV-1. STANDARD SIZES OF MULTIPLE HEARTH FURNACE UNITS

Effective hearth area, sq ft	Outer diameter ft	Number hearths	Effective hearth area, sq ft	Outer diameter ft	Number hearths
85	6.75	6	988	16.75	7
98	6.75	7	1041	14.25	11
112	6.75	8	1068	18.75	6
125	7.75	6	1117	16.75	8
126	6.75	9	1128	14.25	12
140	6.75	10	1249	18.75	7
145	7.75	7	1260	16.75	9
166	7.75	8	1268	20.25	6
187	7.75	9	1400	16.75	10
193	9.25	6	1410	18.75	8
208	7.75	10	1483	20.25	7
225	9.25	7	1540	16.75	11
256	9.25	8	1580	22.25	6
276	10.75	6	1591	18.75	9
288	9.25	9	1660	20.25	8
319	9.25	10	1675	16.75	12
323	10.75	7	1752	18.75	10
351	9.25	11	1849	22.25	7
364	10.75	8	1875	20.25	9
383	9.25	12	1933	18.75	11
411	10.75	9	2060	20.25	10
452	10.75	10	2084	22.25	8
510	10.75	11	2090	18.75	12
560	10.75	12	2275	20.25	11
575	14.25	6	2350	22.25	9
672	14.25	7	2464	20.25	12
760	14.25	8	2600	22.25	10
845	16.75	6	2860	22.25	11
857	14.25	9	3120	22.25	12
944	14.25	10			

Reference: US EPA, Computerized Design and Cost Estimation for Multiple Hearth Sludge Incinerators, 17071 EBP 07/71

design variations

Other variations are related to dewatering equipment selection. Dewatering may be accomplished by centrifuge, vacuum filter, or filter press. Operation and maintenance of these units is described in other sections.

There are two options for handling ash from the furnace. One is to provide a storage hopper and unload dry ash to trucks. The other is to add water and handle ash as a slurry with the slurry being pumped to a lagoon.

A cross section of a typical multiple hearth furnace is shown on Figure XV-1 (see following page). A typical system schematic is shown on Figure XV-2 (see following pages).

There are few variations in the furnace design other than hearth diameter and number of hearths. The two major manufacturer's equipment is very similar, therefore, this manual will be more specific than some of the other manuals.

TYPICAL DESIGN CRITERIA AND PERFORMANCE

Loading rates for several types of sludge are shown in Table XV-2.

TABLE XV-2. MULTIPLE HEARTH FURNACE LOADING RATES

Type of sludge	Solids %	Volatile solids, %	Chemical concentration,* mg/l	Typical wet sludge loading rate,** lb/hr/sq ft
1. Primary	30	60	N/A	7.0-12.0
2. Primary + $FeCl_3$	16	47	20	6.0-10.0
3. Primary + low lime	35	45	298	8.0-12.0
4. Primary + WAS	16	69	N/A	6.0-10.0
5. Primary + (WAS + $FeCl_3$)	20	54	20	6.5-11.0
6. (Primary + $FeCl_3$) + WAS	16	53	20	6.0-10.0
7. WAS	16	80	N/A	6.0-10.0
8. WAS + $FeCl_3$	16	50	20	6.0-10.0
9. Digested primary	30	43	N/A	7.0-12.0

* Assumes no dewatering chemicals.

** Low number is applicable to small plants, high number is applicable to large plants.

The data in this table developed from manufacturers' information.

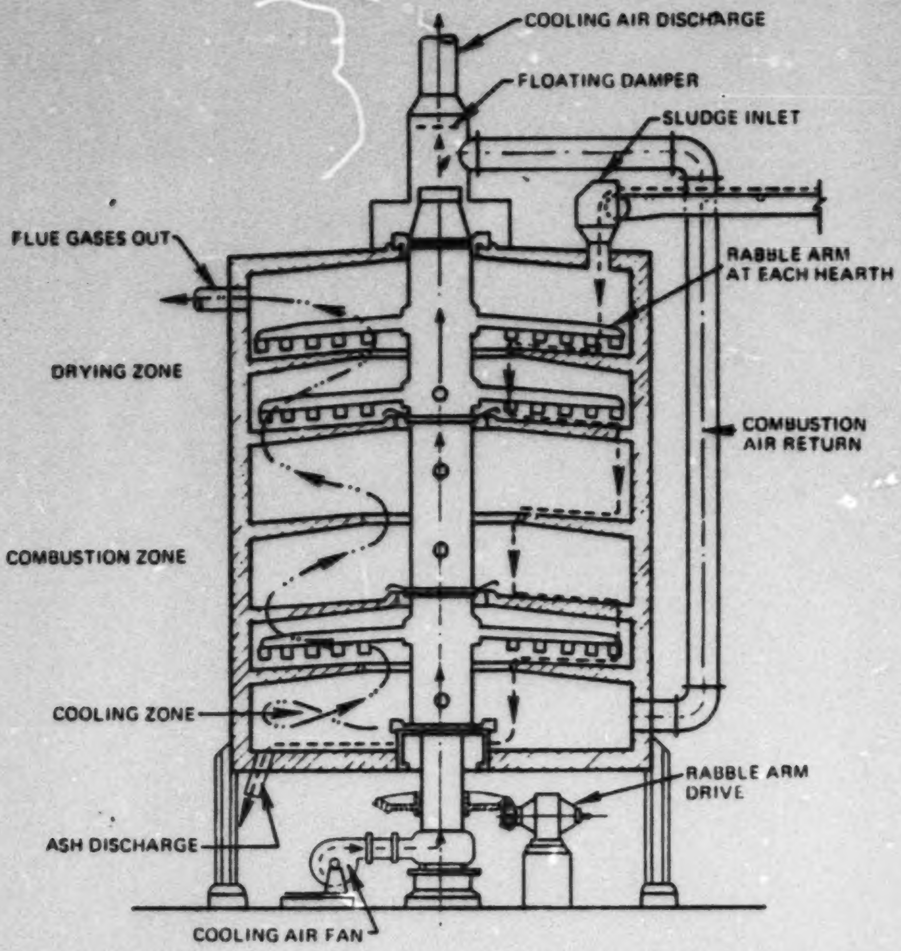

COOLING AIR DISCHARGE
FLOATING DAMPER
SLUDGE INLET
FLUE GASES OUT
RABBLE ARM AT EACH HEARTH
DRYING ZONE
COMBUSTION AIR RETURN
COMBUSTION ZONE
COOLING ZONE
RABBLE ARM DRIVE
ASH DISCHARGE
COOLING AIR FAN

Figure XV-1. Cross section of a typical multiple hearth incinerator.

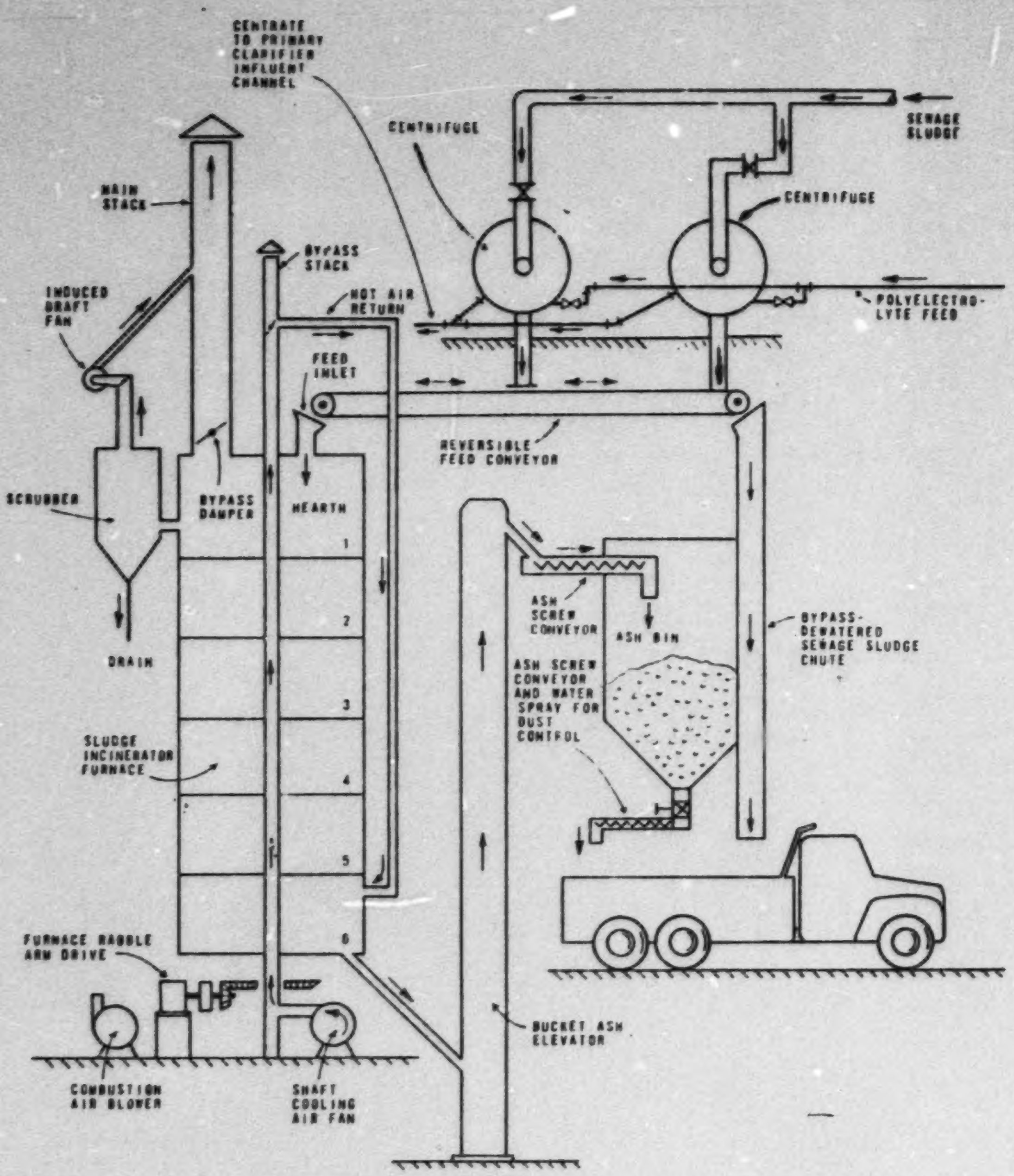

CENTRATE TO PRIMARY CLARIFIER INFLUENT CHANNEL
CENTRIFUGE
SEWAGE SLUDGE
CENTRIFUGE
MAIN STACK
BYPASS STACK
INDUCED DRAFT FAN
HOT AIR RETURN
POLYELECTROLYTE FEED
FEED INLET
REVERSIBLE FEED CONVEYOR
SCRUBBER
BYPASS DAMPER
HEARTH
1
2
3
4
5
6
DRAIN
ASH SCREW CONVEYOR
ASH BIN
BYPASS-DEWATERED SEWAGE SLUDGE CHUTE
ASH SCREW CONVEYOR AND WATER SPRAY FOR DUST CONTROL
SLUDGE INCINERATOR FURNACE
FURNACE RABBLE ARM DRIVE
BUCKET ASH ELEVATOR
COMBUSTION AIR BLOWER
SHAFT COOLING AIR FAN

Figure XV-2. Typical system schematic.

ash

The volume reduction by sludge incineration is over 90 percent when compared to the volume of dewatered sludge. The ash from the incineration process is free of pesticides, viruses and pathogens. Metals will be converted to the less soluble oxide form or volatilized. The ash can be transported in the dry state to appropriate landfill sites or used as a soil conditioner.

sidestream

The critical sidestream treatment requirement is the flue gas treatment. The scrubbed gases should meet the most stringent air quality requirements. A comparison of scrubbed gas quality with Los Angeles County Air Pollution Control District Rule 53 is shown in Table XV-3.

TABLE XV-3. STACK SAMPLING RESULTS, MULTIPLE HEARTH INCINERATOR WITH COMBINATION LIME-ORGANIC SOLIDS FEED

	Test A	Test B	Test C	Rule 53
Combustion contaminants, grains/SCFM at 12% CO_2	.026	.016	.014	0.3
Oxides of sulfur: (as SO_2), ppm	2.2	2.3	3.2	2000
Oxides of nitrogen (as NO_2), ppm	52	65	-	-

Tests made at South Lake Tahoe Public Utility District, CA, on November 10, 1970.

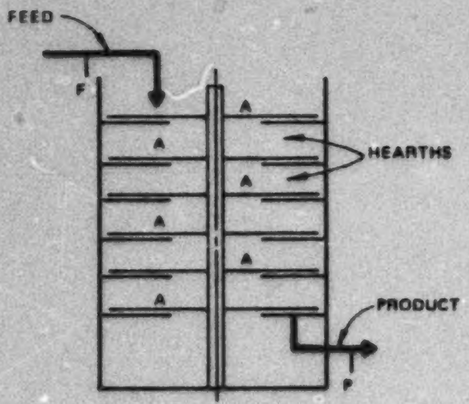
STAFFING REQUIREMENTS

The labor requirements shown in Table XV-4 are based on a high degree of automation of this process and include operation of the furnace, scrubber, and ash handling units.

TABLE XV-4. MULTIPLE HEARTH FURNACE LABOR REQUIREMENTS

Number of units	Labor, hr/yr Operation	Maintenance	Total
1	2,920	1,460	4,380
3	8,760	4,380	13,140
5	14,600	7,300	21,900

MONITORING



SLUDGE TREATMENT SUGGESTED MINIMUM

	TEST FREQUENCY	LOCATION OF SAMPLE	METHOD OF SAMPLE	REASON FOR TEST
TEMPERATURE	Mn	A	Mn	P
TOTAL VOLATILE SOLIDS	1/D[1]	F P	G	P
TOTAL SOLIDS	1/D[1]	F P	G	P

A. **TEST FREQUENCY**

Mn - MONITOR CONTINUOUSLY
D - DAY

B. **LOCATION OF SAMPLE**

F FEED
P - PRODUCT
A - FURNACE ATMOSPHERE (AT EACH HEARTH)

C. **METHOD OF SAMPLE**

Mn - MONITOR CONTINUOUSLY
G - GRAB SAMPLE

D. **REASON FOR TEST**

P - PROCESS CONTROL

E. **FOOTNOTES:**

1. WHEN FURNACE IS OPERATING.

NORMAL OPERATING PROCEDURES (For six hearth furnace)

Initial Inspection

1. Look in feed chute access door above furnace for left-over or caked feed material, obstructions, or debris.
2. Look in each hearth to see that the rabble arms and teeth are in good condition, that clearance is being maintained between teeth and hearths, and that no obstructions exist. See that the hearth refractory is in good condition.
3. Check that each burner shutoff valve is closed and each individual air butterfly valve in lines to each burner is closed. Do not adjust air valve to burner pilot because it has already been reset for proper operation.
4. See that all burner tiles are free of slag accumulations.
5. Check that bottom gas seal around center shaft is filled with sand.

Drying Out Process

1. Following furnace inspection, the furnace should be dried out. The purpose of drying out is to remove moisture from the refractory lining of the furnace and interconnecting flues. Long refractory life is dependent upon proper removal of this moisture as slowly as possible. The best way of doing this is to maintain a low heat throughout the entire furnace during the drying stage.
2. The operator should monitor temperatures frequently to insure that the heating takes place as uniformly as possible; always remember that the heat from the burners travels up through the furnace and is distributed over the upper hearths. The temperature of the gases leaving the furnace should not exceed 400°F for the first 48 hours and should not exceed 500°F at any time during the drying out operation.

   Temperatures on the upper hearth must be high enough to avoid condensation of moisture. The drying out period should be approximately 5 days.
3. The furnace draft during the drying operation should be high enough only to prevent smoke from passing from the furnace into the room. This provides maximum efficiency during the drying operation since the hot gases will not be drawn out of the furnace too fast.

4. Normally, this drying operation should be the first step of a continuous procedure for heating up and putting the furnace into operation.

Startup

1. Turn on center shaft lubrication.
2. Turn on scrubber water supply and adjust to proper flow.
3. Open water supply valve to pre-cooler.
4. Start furnace induced draft fan.
5. Start combustion air fan. Regulate scrubber inlet damper to maintain slightly negative draft on furnace.
6. Start shaft cooling air fan.
7. Check furnace center shaft drive for proper lubrication, proper sand seal, and shear pin position.
8. Turn on manual main safety gas valve. Check to make sure bypass is closed. Check gas meter reading and record reading in plant log.
9. During initial startup and furnace dry out, close slide gate to cooler.
10. Start furnace center shaft drive.
11. The purge cycle should start. Check panel to determine when purge is complete.
12. Open automatic main safety shut off gas valve. This should energize indicator light on furnace control panel.
13. Furnace is now ready for burner to be lit.
14. Light burner according to manufacturer's procedure.
15. For initial startup and dry out, temperature should be increased slowly as described previously. Additional burners could be lit if needed to maintain temperatures and temperature distribution throughout furnace.
16. During initial dry out, the furnace can be operated with the scrubber bypassed and induced draft fan shutdown. The furnace is now operating under natural draft conditions. Draft gauge should indicate a slightly negative pressure (0.08 to 0.10 inches of water column).

17. When furnace is dried out and ready for sludge feed, the scrubber and induced draft fan should be started up.

18. When bringing furnace up to temperature leave burner on minimum fire until temperature rises at rate of 50°F per hour or less. Then place temperature controller in operation with the set point 50°F above the actual temperature. Continue to increase the set point in 50°F increments until hearths 4 and 5 reach desired temperature.

19. Light burners on hearths numbers 2 and 3 as required to bring hearth number 2 to operating temperature and hearth number 3 to operating temperature with rate of increase in temperature not exceeding 50°F per hour. Light burners on hearth number 6 to obtain temperature of 750°F.

20. Adjust scrubber inlet damper controller on induced draft fan outlet to maintain a furnace draft of -0.15 inches water column.

21. Be sure that no burner flame is impinging on any stationary part of the interior of the furnace.

22. Start up sludge conveying system.

23. Begin sludge feed to furnace.

Routine Operations

1. Every two hours, inspect the furnace operation.

    a. Check instrument panel readings. If any change has occurred since previous inspection, reason for change should be determined and corrective action taken if necessary. Enter data in inspection log.

    b. Check top of furnace for squeeling top bearing (lubrication needed) or sludge feed blockage indicated by a buildup in the feed chute.

    c. Look in each burner port for slagging of tiles or other unexpected burner condition.

    d. Look into each hearth on which burners are lit to see that flame characteristics are normal.

    e. Look into hearth number 6 for signs of discharge chute blockage.

f. Check for signs of sludge leakage around center shaft evidenced by a pile of sludge on center shaft drive gear.

g. Frequently monitor the temperature of the ash discharge from the cooler and temperature of cooling water discharge.

h. Check that center shaft cooling fan is running.

i. See that all instrument readings are at desired control points and that none exceed safe limits.

Shutdown

1. The furnace should be shut down and the burners shut off only when necessary. If the sludge feed is to be interrupted temporarily, the furnace should be kept at operating temperature.
2. Stop sludge feed.
3. Twenty minutes later, turn off all burners on hearths numbers 2, 3, and 4. Be sure to close butterfly valves at unused burners.
4. Adjust the exhaust damper to a condition of zero draft.
5. When all sludge has rabbled out of the furnace, the furnace temperature will slowly decline. Keep the center shaft running at all times.
6. Shut off burners at hearths number 5 and 6.
7. When all furnace temperatures are below 500°F, turn off center shaft drive, center shaft cooling fan, and induced draft fan.

CONTROL CONSIDERATIONS

Physical Control (for typical automated system)

Automatic temperature controllers are provided to modulate each bank of burners to a set point temperature. All burners on each fired hearth are controlled through the use of one temperature controller. A low fire start interlock is incorporated into the system.

temperature control

A temperature controller senses the furnace gas outlet temperature and controls this temperature to a preset set point by modulating a control valve on the auxiliary combustion air fan. On increasing temperature, the valve opens to admit more air to the furnace. When the valve is fully opened, a second motor is activated to modulate a lower inlet on the furnace and admit room air on increasing temperature. A manual override is provided to permit adjustment from the control panel on a manual basis.

draft control

Automatic indicating draft control is provided to maintain a pre-set pressure at the gas outlet from the furnace.

The controller senses the pressure and positions a damper in the incinerator induced draft fan outlet. The damper can normally be controlled manually if desired.

draft gauges

Draft pressure indication is normally provided for the following points:

1. Furnace gas outlet
2. Scrubber inlet
3. Differential across scrubber
4. Scrubber outlet

The draft pressure is indicated in inches of water, with a range to suit the application.

flame safety

A complete flame safety system is provided to assure safe operation of the furnace. The system includes a draft switch, shaft cooling air sensor, purge timer and necessary interlocks for fuel, air pressure, and other critical parameters. The system includes low fire start, interrupted ignition, ultraviolet scanners, and similar features. Individual burner panels are normally provided adjacent to each burner or set of burners for a hearth and contain the controls for that burner(s).

temperature recording

Temperatures are normally recorded on a multipoint recorder for the following points:

1. Each hearth
2. Quencher inlet
3. Scrubber inlet
4. Scrubber outlet
5. Incinerator central shaft cooling air outlet
6. Incinerator exhaust stack outlet

shaft rotation

Shaft rotation is monitored by a "telltale" device to signal any interruption of the shaft rotation. The conveyor system is normally interlocked to center shaft rotation so sludge feed is stopped if the center shaft stops.

scrubber temperature

The scrubber outlet temperature is normally indicated and usually a high alarm switch stops the induced draft fan and opens the emergency vent.

ash

Ash level is monitored in the storage bin by a device to sound an alarm on high level.

alarms

An annunciator system is normally furnished to accommodate all the necessary alarm points.

The furnace feed rate is normally indicated and/or recorded.

Process Control

solids handling system

An incinerator is usually part of a sludge treatment system which includes sludge thickening, macerations dewatering (such as vacuum filter, centrifuge, or filter press), an incinerator feed system, air pollution control devices, ash handling facilities, and the related automatic controls. The operation of the incinerator cannot be isolated from these other system components. Of particular importance is the operation of the thickening and dewatering processes because the moisture content of the sludge is the primary variable affecting the incinerator fuel consumption.

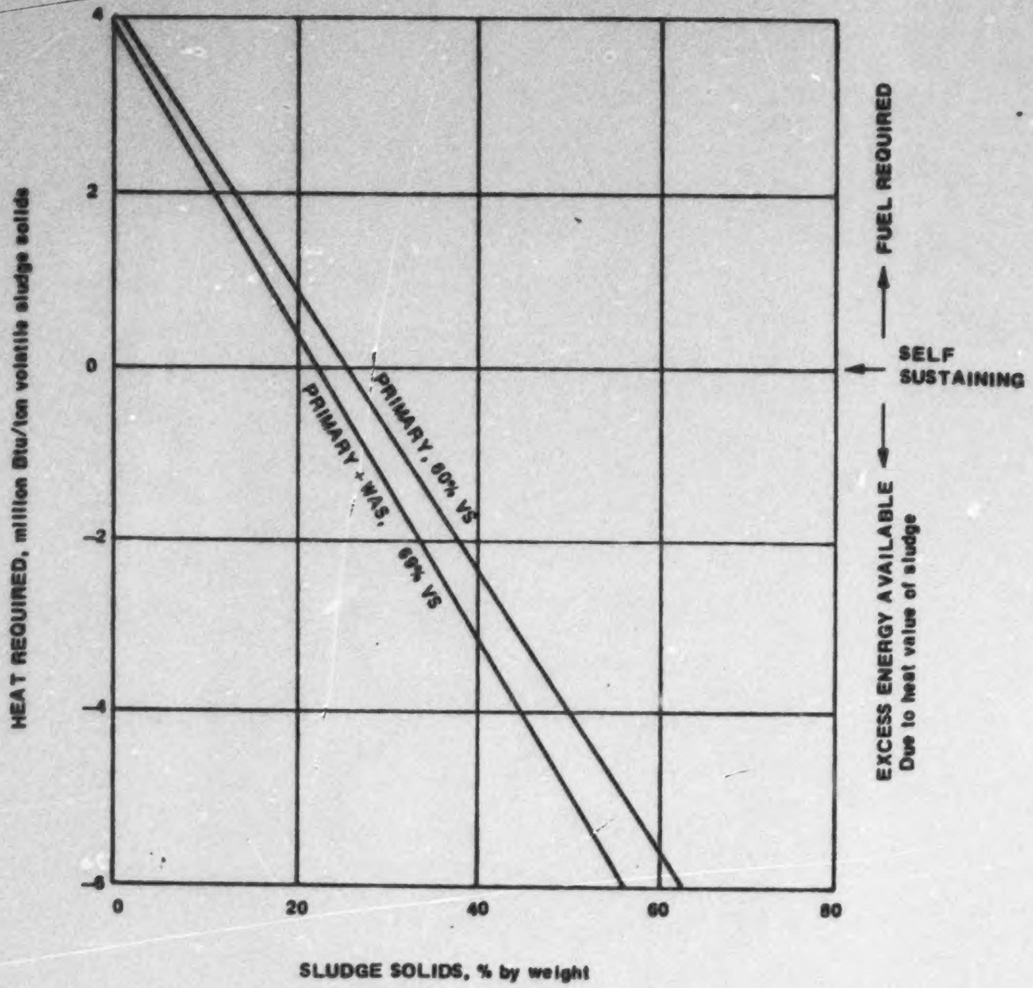
effect of moisture

The relationship between auxiliary fuel required and feed sludge solids concentration is shown in Figure XV-3 (see following page) for typical primary sludges and primary plus waste activated sludges. Typically, incineration is self sustaining at sludge solids concentrations of about 26 percent for primary sludge and 23 percent for primary plus WAS. Incineration will always require some fuel because of startup requirements. Fuel requirements will be substantially higher if afterburner operation is required.

As shown in Figure XV-3, incineration is self sustaining (no fuel required) when the sludge contains less than 75 percent moisture when no afterburner is used.

sludge fuel value

The fuel value of the sludge itself is also important in determining fuel consumption. Typical heat values of various sludges are:



- Assumed heat value of sludge: 10,000 Btu/lb of volatile solids
- Curve assumes that afterburner is not used.

Figure XV-3. Auxiliary heat required to sustain combustion of sludge.

Type of sludge	Heating value, (Btu/lb of dry solids)
Raw primary	10,000-12,500
Activated	8,500-10,000
Anaerobically digested primary	5,500
Raw (chemically precipitated) primary	7,000
Biological filter	8,500-10,000
Grease and scum	16,700
Fine screenings	7,800
Ground garbage	8,200
High organic grit	4,000

As the percentage of volatiles increases, the auxiliary fuel consumption decreases for a given sludge. The volatile content of a sludge may be maximized by removing sludge inorganics such as grit, by avoiding the use of inorganic chemicals such as ferric chloride and lime in the dewatering process, and by avoiding biological processes such as digestion before incineration.

In normal operation, a multiple hearth furnace provides three distinct combustion zones:

1. Two or more upper hearths on which most of the free moisture is evaporated.

hearths

2. Two or more intermediate hearths on which sludge burns at temperatures exceeding 1,500°F.
3. A bottom hearth that serves as an ash cooling zone by giving up heat to the cooler incoming air.

During evaporation of moisture in the first zone the sludge temperature is not raised higher than about 140°F. At this temperature no significant quantity of volatile matter is driven off, and hence no obnoxious odors are produced. Distillation of volatiles from sludge containing 75 percent moisture does not occur until 80 to 90 percent of the water has been driven off and, by this time, the sludge is down far enough in the incinerator to encounter gases hot enough to burn the volatiles which could cause odors. Generally, when fuel is required to maintain combustion in a multiple hearth furnace, a gas outlet temperature above 900°F indicates too much fuel is being burned.

excess air

Practical operation of an incinerator requires that air in excess of theoretical requirements for combustion be supplied to the combustion chamber. This increases the opportunity of contact between fuel and oxygen which is necessary if combustion is to proceed. When the amount of excess air is inadequate, only partial combustion occurs, resulting in the formation of carbon monoxide, soot, and odorous hydrocarbons in the stack gases. Multiple hearth incineration is typically operated at 75 to 100 percent excess air. Excess air in the 100 to 200 percent range is undesirable because it wastes fuel. A closely controlled minimum excess air flow is desirable for maximum thermal economy.

stack gas

Analysis of stack gas composition is typically used to control excess air. Oxygen, carbon dioxide, and carbon monoxide may be monitored automatically in the stack and compared with target levels. If the carbon monoxide level increases, this indicates that incomplete combustion is occurring and more excess air may be needed. However, if the oxygen level is within proper range, either the mixing of sludge and combustion air is inadequate or the temperature has been reduced by the addition of cake that is wetter than normal.

sensory

The stack gas appearance can indicate problems with the scrubber or furnace operation. If the stack gas contains excessive particulate concentrations there will be a brown or black plume. If odors are emitted, the combustion process is not complete.

Another sensory indicator is the color of the ash. If a change occurs, there may have been a chemical change in the raw sewage entering the plant or the combustion process may not be properly adjusted. Similarly, odors produced by the ash may indicate incomplete combustion.

furnace shutdown

A furnace should not be shut down and cooled unless absolutely necessary because of the stresses placed on the refractory. If cooling of the furnace is necessary it should be done slowly and strict startup procedures should be followed.

EMERGENCY OPERATING PROCEDURES

Loss of Power

Emergency generation or auxiliary engine drives must be provided for at least the shaft cooling air fan and center shaft drive. It is desirable to provide adequate standby facilities so the furnace can be kept on line and up to temperature.

Loss of Fuel

The natural gas service to the treatment plant may be interruptible. That is, in times of high demand in the area for natural gas, the gas service can be temporarily interrupted. Ordinarily, notice would be given a day or so in advance by the gas company, who might also give an estimate of the probable duration of the shutdown.

Propane gas may be used as backup to the natural gas supply. It is wise to have a backup fuel system because of the time required to bring the furnace up to temperature after it has shut down and cooled.

Loss of Other Treatment Units

The most critical treatment unit prior to incineration is dewatering. Normally, multiple units allow continued dewatering with one unit out of service. If more than one unit is out of service the sludge moisture content may increase. It may be possible to increase chemical addition to the overloaded units to improve dewatering performance. If not, the furnace auxiliary fuel feed will be higher because of the larger volume of water.

If the scrubber is out of service, the furnace should not be operated, but may be kept up to temperature, if desired. If the scrubber is not functioning properly, the excess air can be increased to reduce particulate concentrations.

COMMON DESIGN SHORTCOMINGS

Shortcoming	Solution
1. Poor dewatering efficiency. (See Table XV-2 for optimum efficiencies).	1a. Try various chemical conditions.
	1b. Add additional dewatering units.
	1c. Accept lower solids, concentration, increase fuel.
2. Reactor undersized.	2a. Operate incinerator for longer period of time.
	2b. Improve sludge dewatering prior to incineration.

Shortcoming	Solution
3. Inadequate storage for raw sludge when reactor is out of service.	3a. Store sludge in clarifiers or thickeners (temporary). 3b. Haul sludge to landfill.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Furnace temperature too high.	1a. Excessive fuel feed rate.	1a. Fuel feed rate.	1a. Decrease fuel feed rate.
	1b. Greasy solids.	1b. If fuel is off and temperature is rising, this may be the cause.	1b. Raise air feed rate or reduce sludge feed rate.
	1c. Thermocouple burned out.	1c. If temperature indicator is off scale, this is the likely cause.	1c. Replace thermocouple.
2. Furnace temperature too low.	2a. Moisture content of sludge has increased.	2a. Moisture content and dewatering system operation.	2a. Increase fuel feed rate until dewatering system operation is improved.
	2b. Fuel system malfunction.	2b. Check fuel system.	2b. Establish proper fuel feed rate.
	2c. Excessive air feed rate.	2c. If oxygen content of stack gas is high, this is likely the cause.	2c. Reduce air feed rate or increase feed rate.
3. Oxygen content of stack gas is too high.	3a. Sludge feed rate too low.	3a. Check for blockage of sludge feed system and check feed rate.	3a. Remove any blockages and establish proper feed rate.
	3b. Air feed rate too high.	3b. Air feed rate.	3b. Decrease air feed rate.
4. Oxygen content of stack gas is too low.	4a. Volatile or grease content of sludge has increased.	4a. Sludge composition.	4a. Increase air feed rate or decrease sludge feed rate.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	4b. Air feed rate too low.	4b. Check for malfunction of air supply and check feed rate.	4b. Increase air feed rate.
5. Furnace refractories have deteriorated.	5. Furnace has been started up and shutdown too quickly.	5. Operating records.	5. Replace refractories and observe proper heating up and cooling down procedures in future.
6. Unusually high cooling effect from one hearth to another.	6. Air leak.	6. Hearth doors, discharge pipe, center shaft seal, air butterfly valves in inactive burners.	6. Stop leak.
7. Short hearth life.	7. Uneven firing.	7. Check all burners in hearth.	7. Fire hearths equally on both sides.
8. Center shaft drive shear pin fails.	8. Rabble arm is dragging on hearth or foreign object is caught beneath arm.	8. Inspect each hearth.	8. Correct cause of problem and replace shear pin.
9. Furnace scrubber temperature too high.	9. Low water flow to scrubber.	9. Scrubber water flow.	9. Establish adequate scrubber water flow.
10. Stack gas temperatures too low (500-600°F) and odors noted.	10. Inadequate fuel feed rate or excessive sludge feed rate.	10. Fuel and sludge feed rates.	10. Increase fuel or decrease sludge feed rates.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
11. Stack gas temperatures too high (1,200-1,600°F).	11. Excess heat value in sludge or excessive fuel feed rate.	11. Sludge characteristics and fuel rate.	11. Add more excess air or decrease fuel rate.
12. Furnace burners slagging up.	12. Burner design.	12. Consult with manufacturer.	12. Replace burners with newer designs which minimize slagging.
13. Rabble arms are drooping.	13. Excessive hearth temperatures or loss of cooling air.	13. Operating records; is grease or scum being injected into the hearth.	13. Maintain temperatures in proper range and maintain backup systems for cooling air in working condition; discontinue scum injection into hearth.

MAINTENANCE CONSIDERATIONS

A good preventive maintenance program will reduce breakdowns which could be not only costly, but also very unpleasant for operating personnel. A good preventative maintenance program is very important for an incinerator because of the large drives and the need to minimize incinerator shutdowns. The following are the major elements which should receive regular attention for wear, corrosion, proper adjustment, and lubrication according to manufacturer guidelines.

1. Drives and gear reducers
2. Chains and sprockets
3. Burners
4. Air blowers
5. Sludge conveying equipment
6. Ash conveying equipment *mechanical*
7. Furnace seals
8. Draft controller
9. Temperature controllers
10. Any standby engine drives or generators
11. Scrubber

SAFETY CONSIDERATIONS

Safety measures should include the following:

1. No smoking should be allowed around the natural gas lines or when checking the system for leaks.

2. Protective clothing and face shields should be worn when repairing or lighting the furnaces.

3. A colored plate should be used when looking into an operating hearth to protect the eyes from the bright flame.

4. Open hearth access doors with caution, do not stand in front of them when they are initially opened, and close them as soon as possible.

REFERENCE MATERIAL

References

1. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, 1015 Eighteenth Street, N.W., Washington, D.C. 20036.

2. Computerized Design and Cost Estimation for Multiple Hearth Sludge Incinerators by Unterberg, et al. (U.S. EPA, 17070 EBP 07/71). Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Glossary of Terms and Sample Calculations

1. Excess Air is the amount of air required beyond the theoretical air requirements for complete combustion. This parameter is expressed as a percentage of the theoretical air required.

   Sample calculation for excess air:

$$\text{excess air} = \frac{(\text{actual air rate})(\text{theoretical rate}) \times 100}{\text{theoretical air rate}}$$

$$= \frac{(1{,}500 - 1{,}000) \times 100}{1{,}000}$$

$$= 50\%$$

2. Sludge loading rate is the weight of wet sludge fed to the reactor per square foot of reactor bed area per hour (lb/sq ft/hr).

   Sample loading rate:

$$\text{loading rate} = \frac{\text{lb sludge/hr}}{\frac{\pi d^2}{4}} \left(\frac{100}{\%\ \text{moisture content}}\right)$$

$$= \frac{440}{\frac{3.14\ (20)^2}{4}} \left(\frac{100}{20}\right)$$

$$= 7.01\ \text{lb/sq ft/hr}$$

3. Solids concentration is the weight of solids per unit weight of sludge. It is calculated as follows:

$$\text{concentration} = \frac{\text{weight of dry sludge solids} \times 100}{\text{weight of wet sludge}}$$

$$= \frac{25 \times 100}{120}$$

$$= 20.8\%$$

4. __Moisture content__ is the amount of water per unit weight of sludge. The moisture content is expressed as a percentage of the total weight of the wet sludge. This parameter is equal to 100 minus the percent solids concentration or can be computed as follows:

moisture content =

$$\frac{\text{(weight of wet solids)} - \text{(weight of dry solids)} \times 100}{\text{weight of wet solids}}$$

$$= \frac{(120 - 25) \times 100}{120}$$

$$= 79.2\%$$

XVI

FLUIDIZED BED INCINERATION

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PROCESS DESCRIPTION

The fluidized bed incinerator is a vertical cylindrical vessel with a grid in the lower section to support a sandbed. Dewatered sludge is injected above the grid and combustion air flows upward at a pressure of 3.5 to 5.0 psig and fluidizes the mixture of hot sand and sludge. Supplemental fuel can be supplied by burners above or below the grid. In essence, the reactor is a single chamber unit where both moisture evaporation and combustion occur at 1,400 to 1,500°F in the sandbed. All the combustion gases pass through the 1500°F combustion zone with residence times of several seconds. Ash is carried out the top with combustion exhaust and is removed by air pollution control devices.

operation

The quantities of excess air are maintained at 20 to 25 percent to minimize its effect on fuel costs. The heat reservoir provided by the sandbed enables reduced start-up times when the unit is shut down for relatively short periods (overnight). As an example, a unit can be operated 4 to 8 hours a day with little reheating when restarting, because the sandbed serves as a heat reservoir.

Exhaust gases are usually scrubbed with treatment plant effluent and ash solids are separated from the liquid in a hydrocyclone, with the liquid stream returned to the head of the plant and the ash further dewatered mechanically or in a lagoon.

design differences

There are two major variations in the reactor design. These are the actual point of sludge feed and use of a preheater or heat exchanger. The sludge feed point can be at a bed level or at the top of the reactor. Most models produced now include a heat exchanger which preheats incoming sludge thus reducing fuel requirements. This manual is written with the sludge feed point at bed level and with the heat exchanger included.

Other variations are found in the types of dewatering devices used prior to incineration. Operation and maintenance of these devices have been discussed in earlier sections (centrifuge, vacuum filter, and filter press).

A cross section of a typical fluid bed reactor is shown on Figure XVI-1 (see following page). A schematic of a typical complete system is shown on Figure XVI-2 (see following page). This manual applies to all those unit processes

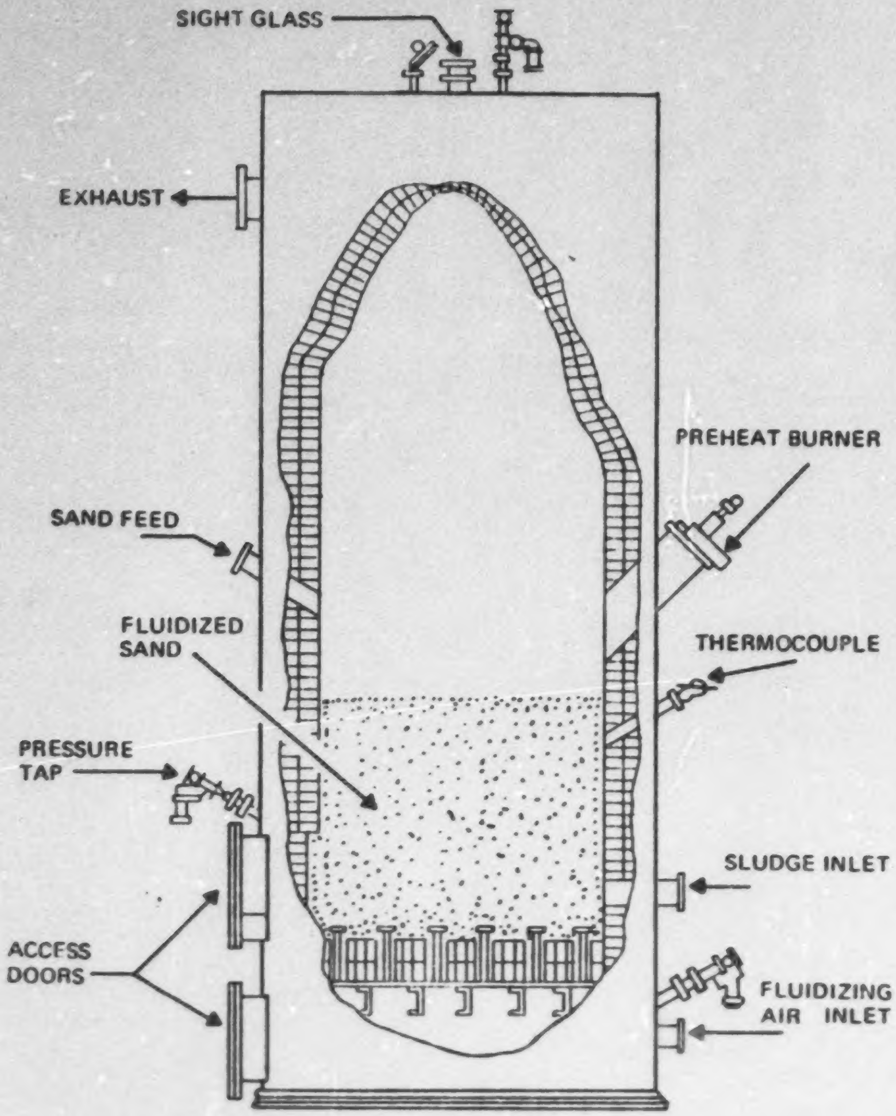
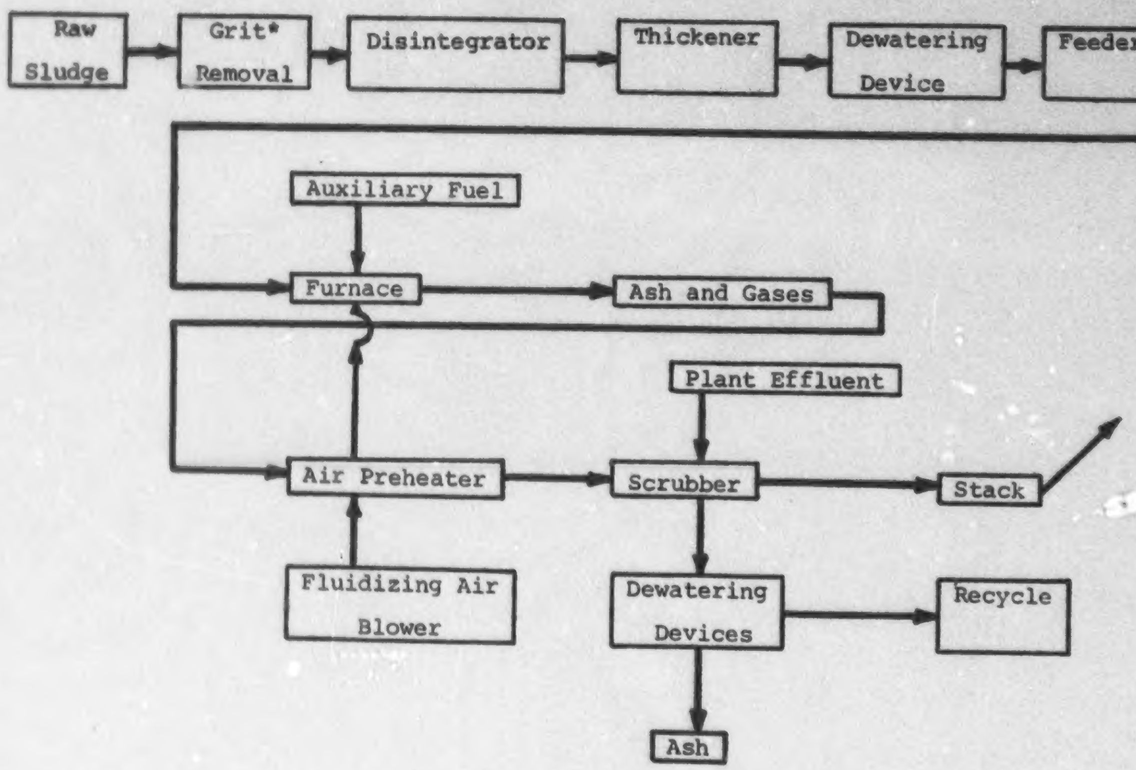

SIGHT GLASS
EXHAUST
PREHEAT BURNER
SAND FEED
FLUIDIZED SAND
THERMOCOUPLE
PRESSURE TAP
SLUDGE INLET
ACCESS DOORS
FLUIDIZING AIR INLET

Figure XVI-1. Cross section of a fluid bed reactor.


Raw Sludge
Grit* Removal
Disintegrator
Thickener
Dewatering Device
Feeder
Auxiliary Fuel
Furnace
Ash and Gases
Plant Effluent
Air Preheater
Scrubber
Stack
Fluidizing Air Blower
Dewatering Devices
Recycle
Ash

* If not included in plant headworks

Figure XVI-2. Fluidized bed furnace system schematic

shown on Figure XVI-2 except the grit removal, disintegrator, thickener, and dewatering device.

sidestreams

There are several sidestreams from the thickening and dewatering units. These sidestreams and their treatment methods are presented in other sections. The material leaving the furnace consists of ash and gas. This mixture is treated by a scrubber which separates the two products. Gas is then vented through a stack.

The scrubber produces a mixture of water and ash. The ash is then concentrated, dewatered, and hauled to disposal. The water is recycled to the headworks.

TYPICAL DESIGN CRITERIA AND PERFORMANCE

Typical loading rates for various types of sludge are shown on Table XVI-1. The loading rates are a function of the moisture content of the feed sludge.

TABLE XVI-1. LOADING RATES

Type of sludge	Solids, %	Vol. solids, %	Chemical concentration,* mg/l	Wet sludge loading rate, lb/sq ft/hr
Primary	30	60	N/A	14
Primary + $FeCl_3$	16	47	20	6.8
Primary + low lime	35	45	298	18
Primary + WAS	16	69	N/A	6.8
Primary + (WAS + $FeCl_3$)	20	54	20	8.4
(Primary + $FeCl_3$) + WAS	16	53	20	6.8
WAS	16	80	N/A	6.8
WAS + $FeCl_3$	16	50	20	6.8
Digested primary	30	43	N/A	14

*Assumes no dewatering chemicals.

Using the loading rates shown, the ash and gas products characteristics should be fairly consistent. These products are mainly a function of the combustion temperature. In order to deodorize the stack gas a temperature of 1,350 to $1,400^{\circ}$F must be maintained. At these temperatures the sludge is completely burned assuming the furnace is not overloaded. Therefore, the measure of performance is the stack gas quality. The gas quality is measured in terms of particulates, metals, gaseous pollutants, and organic compounds. The scrubber is designed to remove particulates with the ash. Most metals present in municipal sludges are converted to oxides which appear in the particulates removed by the scrubber. Lead and mercury are two exceptions. These two metals vaporize and will appear in the stack gas if present in the sludge. Carbon monoxide is present in the stack gas only if the furnace is improperly designed or operated. Another gaseous indicator of furnace performance is the presence of toxic substances, such as pesticides or PCB's. Proper operation at temperatures above 1,100°F should destroy PCB's.

STAFFING REQUIREMENTS

The staff requirements are small due to the automation of this process. Labor requirements for operation and maintenance of the reactor, air pre-heater, fluidizing air blower, scrubber, and ash dewatering units are shown on Table XVI-2.

TABLE XVI-2. LABOR REQUIREMENTS FLUIDIZED BED REACTOR*

Number of reactors	Labor, hr/yr Operation	Maintenance	Total
1	2,920	1,460	4,380
3	8,760	4,380	13,140
5	14,600	7,300	21,900

* Assuming full-time operation 7 days per week, 52 weeks per year.

MONITORING

Most of the furnace process control monitoring is automatic. That is, those critical parameters for furnace operation such as temperature maximum and minimum in the bed and maximum exhaust temperature are monitored continuously with built-in thermocouples. Also, critical to furnace operation is the percent of excess air which is determined by continuous monitoring of the percent oxygen in the stack gas from the scrubber.

Other monitoring requirements are those related to determining process performance and optimization of preprocessing equipment. The monitoring points include incoming sludge to the thickener, dewatering unit, furnace, scrubber, ash concentrator, and ash dewatering unit. The auxiliary/startup fuel line is metered. Sidestreams returning to the plant headwaters from concentration and dewatering units are monitored.

There are also monitoring requirements for regulatory agencies. These include stack gas and ash for disposal.

These monitoring points are shown on Figure XVI-3 (see following page).

The analyses required and their frequency shown on Table XVI-3 for each monitoring point is identified on Figure XVI-3.

TABLE XVI-3. MONITORING

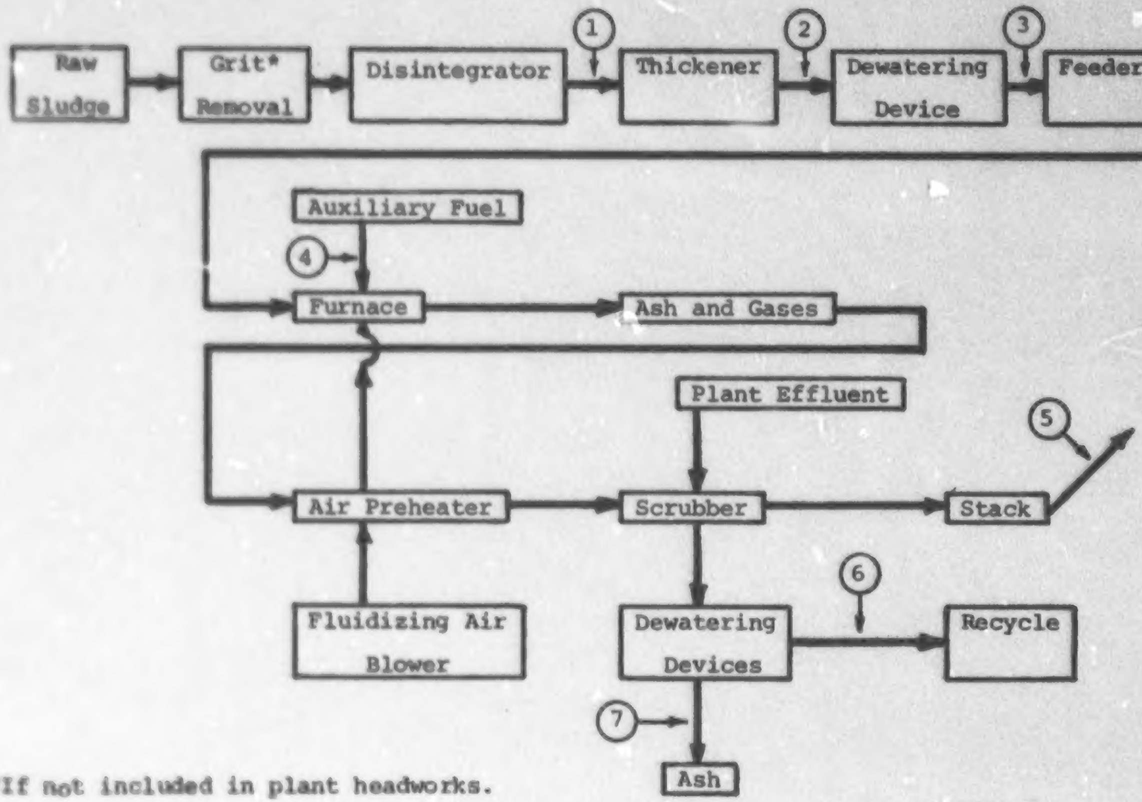
Monitoring point	Analysis	Frequency
1	Solids content	Weekly
2	Solids content	Weekly
3	Solids content	Weekly
3	Volatile solids	Weekly
4	Fuel quantity	Continuous
5	Oxygen content	Continuous
5	Particulate concentration	Weekly
5	Carbon monoxide	Monthly
5	Lead	Semiannual
5	Mercury	Semiannual
5	Hydrogen chloride	Semiannual
5	Sulfur dioxide	Semiannual
5	Oxides of nitrogen	Semiannual
6	BOD_5	Weekly
6	Suspended solids	Weekly
7	Metals content	Semiannual*
7	Moisture content	Weekly

*If ash used for soil conditioner.

Those tests taken for evaluating process performance are accomplished weekly. Those required for regulatory requirements are accomplished less frequently. The regulatory requirements may change depending on the particular jurisdiction.

Sensory Observations

The stack gas appearance can be indicative of a problem with the scrubber or proper operation of the furnace. If


Raw Sludge
Grit* Removal
Disintegrator
1
Thickener
2
Dewatering Device
3
Feeder
Auxiliary Fuel
4
Furnace
Ash and Gases
Plant Effluent
5
Air Preheater
Scrubber
Stack
6
Fluidizing Air Blower
Dewatering Devices
Recycle
7
Ash

*If not included in plant headworks.

Figure XVI-3. Fluidized bed furnace system monitoring points

the stack gas has excessive particulate concentrations there will be a brown or black flume appearing. If there is an odor present then the combustion process is not being completed.

Another sensory indicator is the color of the ash. If a change occurs, there may have been a chemical change in the raw sewage entering the plant or the combustion process may not be complete. Similarly, odors produced by the ash may indicate incomplete combustion.

NORMAL OPERATING PROCEDURES

Startup

Part I - Operating the Preheat Burner

1. Check utilities, power, fuel, water, correct positioning of valves in purge air system and water system.
2. Set all controls at zero or "MANUAL" position.
3. Start oxygen analyzer sample from the reactor exhaust system.
4. Begin water flow to scrubber trays, venturi throat and water seal.
5. Adjust burner atomizing air and combustion air valve. Adjust oil metering valve on preheat burner to a low-fire position. Open manual valves in pilot fuel piping and burner oil piping.
6. Start preheat burner blower.
7. Ignite preheat burner.
8. After a few minutes, gradually increase fuel rate to burner until at full fire.
9. Shut manual valves in pilot fuel line.
10. Continue heating and "bumping" bed to slightly above 1,150°F.
11. Open manual valves in bed gun fuel line.
12. Start fluidizing blower and set air rate at 5,450 SCFM. Check that exhaust oxygen is 4 percent or higher.
13. Shutdown preheat burner.

14. Stop preheat burner blower.
15. Shut manual valves in preheat burner fuel piping.
16. Heat bed to temperature for sludge incineration.

Part II - Reactor Startup When Bed Temperature is Above 1,150°F

1. Check utilities, power, fuel water, correct positioning of valves in purge air system and water system.
2. Set all controls at zero or "MANUAL" position.
3. Start oxygen analyzer sample from reactor exhaust system.
4. Start flow of water to scrubber trays, venturi throat and water seal.
5. Light bed gun burner.
6. Start fluidizing blower. Set air rate at 5,450 SCFM.
7. Start injector purge air blower.
8. Raise gun fuel rate to maximum allowable.
9. Heat bed above auto-ignition temperature of sludge, say 1,300°F.
10. Reduce fuel rate and start sludge feed system. Increase air rate as required.

Part III - Feed System Operation (Reactor has been started and is at least 1,250°F)

1. Set valves for flow of sludge from concentration tank to dewatering device.
2. Check that feed gun valves are in feed position.
3. Check that supply of chemicals is ample and set valves for flow of chemicals.
4. Start dewatering devices and transfer screw conveyors.
5. Start macerator.
6. Start dewatering device feed pumps and adjust speed.
7. Start chemical pumps and dilution water.

8. When dewatering devices deliver sludge in chutes, start reactor feed pumps. DO NOT RUN PUMP DRY!

9. Observe oxygen analyzer. Keep oxygen content at 4 to 6 percent. Adjust sludge and fuel rates as reactor warms up.

Routine Operations

Instructions in this section apply when the reactor has already started, and the bed temperature is above the auto-ignition temperature of the auxiliary fuel. It is assumed that the bed guns are in use and the oxygen analyzer is operating.

Before starting the reactor feed system, the operator should check that the following items are ready:

1. See that the dewatering system is ready for operation and that there is sufficient sludge in the concentration tank to permit a normal operating cycle.

2. Check valves in the sludge lines for correct position.

3. Valves between the concentration tank and the dewatering system inlets should be open.

4. If daily use of polymers is required, check supply of stock solution. Also check that valves are open in the chemical system.

5. Check that the valves are open in the chemical system.

    a. Start the dewatering system.

    b. Start the reactor feed pumps after the following conditions are met:

        (1) Dewatering device feed pumps are running.
        (2) Fluidizing air flow is above 3,900 SCFM.
        (3) Bed teperature is between 1,200°F and 1,600°F.
        (4) Reactor exhaust temperature is below 1,800°F.

        Note: Under *no* circumstances should reactor feed pump be allowed to run dry!

    c. As soon as the dewatered sewage sludge enters the reactor, demand for oxygen will increase and it will be necesary to lower the auxiliary fuel rate. Unless the auxiliary fuel rate is adjusted at this time, the maximum heat release from the sludge will not be achieved and fuel may be wasted. Daily operating experience will soon show exact auxiliary fuel settings at start-up.

d. During the next hour, a series of adjustments can be made as follows:

Gradually increase sludge feed rate to the reactor to the maximum indicated by experience. When changes are made in sludge or auxiliary fuel rate, wait 5 minutes and check oxygen analyzer.

Note: Adjustment of auxiliary fuel and sludge feed rates should be done gradually since reaction time for the bed temperature change can be as long as 15 to 30 minutes.

(1) Reduce fuel rate to the minimum which is necessary to maintain bed temperature in the 1,250 to 1,300°F range.

(2) Chemical feed rate is adjusted so that minimum amount of polymer is used while maintaining a good quality centrate.

(3) Reactor exhaust oxygen should be in the range of 4 to 6 percent for good combustion. This can be done by adjusting the fluidizing air flow rate in very gradual steps. Increasing the air flow rate will increase exhaust oxygen content. Decreasing the air flow rate will decrease exhaust oxygen content. The reaction time for these adjustments is several minutes.

e. At this point, all equipment required for sludge incineration is operating. Maintain hourly readings on log sheet.

Shutdown

Normal shutdown will follow the three groups of steps listed:

1. Reactor feed system shutdown.
2. Heating bed to the maximum allowed by the bed temperature interlocks.
3. Reactor shutdown and scrubber shutdown.

As soon as the reactor feed system is stopped, it is possible to heat the reactor with bed guns for overnight shutdown. The scrubber is then shutdown and a general cleanup started.

1. Shutdown sludge dewatering equipment. While the reactor is still operating, press the reactor feed pump "STOP" and "START" buttons. Pump a mixture of thin sludge and water through the reactor feed system to displace the heavier sludge present in the reactor feed hose. As the water enters the bed, there will be a rise in freeboard pressure. By slowly pumping thin sludge through the feed hose, the reactor sludge gun is cleaned for the next start-up.

2. Close valves on feed guns. Blow out feed guns with compressed air to clear sludge remaining in the feed nozzle.

3. Pumping thin sludge in Step 1 will tend to lower the bed temperature slightly. Continue heating bed until "bed high temperature" alarm sounds.

4. Stop fuel flow. Leave fluidizing blower running and proceed.

5. Close fluidizing air control valve and when the air flow rate is nil, stop fluidizing blower. A solenoid valve will automatically close on the scrubber quench sprays when the blower is stopped.

6. Stop injector purge air blower.

7. Shutdown scrubber by stopping the process water flow, ash pump, ash classifier, and water to the water seal, then drain scrubber.

8. Shutdown oxygen analyzer sample system.

9. Check that manual valves are shut off in the bed gun fuel system and preheat burner fuel system. Check that water valves are closed.

CONTROL CONSIDERATIONS

Physical Control

The fluid bed furnace is furnished with a semi-automatic process control system and a mechanical electrical protection system, which free the operator from continuous supervision. The process is maintained in balance at the required excess *reactor*

air and operating temperatures by normal adjustments in air rate and sludge feed rate, and automatic control of auxiliary fuel rate. The process parameters and physical conditions are kept in check by means of a multi-point alarm system which warns the operator of impending imbalances in the process or mechanical equipment.

The main control panel comes with a two-pen recorder which gives two important indications of how well the plant is operating:

> Bed temperature - When the reactor is operating in equilibrium the bed temperature will vary within a narrow range and neither rise nor fall. A raising or falling bed temperature trend indicates that an adjustment of sludge or oil rates is required.
>
> Oxygen content - If the correct amount of air is being supplied to the reactor, the exhaust oxygen reading will be in the 4 to 6 percent range.

Other process parameters and electrical interlocks are incorporated in the system to prevent starting equipment out of sequence or to automatically shutdown or stop various components of the system, preventing damage to the equipment.

oxygen analyzer

The purpose of the analyzer is to measure the amount of oxygen in the reactor exhaust gas. The amount of oxygen remaining after combustion is a direct measure of the quantity of excess air being supplied to the reactor. The excess air during sludge incineration should vary between 20 to 40 percent during normal operation, with an absolute minimum of 10 percent. Good combustion results when the analyzer indicates 3½ to nearly 6 percent oxygen. Operating at less than 2 percent oxygen (10 percent excess air) must be avoided.

When low oxygen readings occur, the situation is corrected by increasing the air rate slightly. If the fluidizing air blower is already operating at its design capacity, low oxygen readings are corrected by decreasing the fuel rate to the reactor. Remember that sludge is a fuel also, slight adjustments of sludge feed rate and/or auxiliary fuel rate can be made. When all three conditions listed below are satisfied the reactor should be operating efficiently:

1. Reactor exhaust oxygen content between 4 and 6 percent.

2. Bed temperature is steady.

3. Auxiliary fuel rate is at a minimum and sludge feed rate is at maximum.

The reactor needs several hours after startup to warm up and approach the above ideal conditions.

When exhaust oxygen readings are high during sludge incineration, the sludge feed rate should be increased. The auxiliary fuel rate should be adjusted accordingly to maintain a steady bed temperature.

A lapse period of 3 to 5 minutes exists between the oxygen analyzer and any change made in the fuel rate.

An alarm point on the annunciator warns the operator of low exhaust oxygen readings.

bed temperature supervision

The bed temperature is one of the most important instrument readings in the entire fluidized bed furnace system. A series of electrical interlocks prevents operation of the sludge feed system to the reactor when the bed is not within the correct temperature range.

There are usually three thermocouples inserted in the bed. Each is encased by a stainless steel protection tube (called a "thermowell"). The lead wires of two thermocouples are connected to temperature indicators. The sole purpose of these thermocouples is to provide the operator with a direct reading of bed temperature. This reading is a check of the control thermocouple.

The third thermocouple is used for input to the bed temperature controller which controls the fuel rate to the bed guns and the following interlock circuits:

1. To prevent the flow of fuel to the bed gun when the bed temperature is below 1,150°F.
2. To prevent the feed of sludge to the bed when the temperature is below 1,200°F.
3. Low bed temperature alarm, actuated at 1,250°F.
4. High bed temperature alarm. Actuated at 1,550°F.
5. To prevent feed of sewage sludge or auxiliary fuel to the bed when the temperature is above 1,600°F.

Aside from bed temperature supervision the system normally has temperature alarms as follows.

1. High temperature switch in the reactor exhaust set for 1,800°F, which prevents feed of sewage sludge to bed and fuel to either bed guns or preheat burner when activated.

2. High temperature switch in the scrubber inlet set for 550°F. This activates an alarm.

air flow

Air rate measurement is obtained by measuring pressure difference across an orifice plate installed in the inlet pipe to the fluidizing air blower. As the air rate increases, so does the pressure difference across the orifice plate and pointer on the SCFM scale then moves upward on the indicator scale. For decreasing air flows, the reverse is true.

It is undesirable to operate the reactor with too low an air rate because poor bed fluidization and incomplete fuel combustion will result. At low air flow the pressure difference across the orifice plate will stop fuel flow to the fuel guns.

Reactor pressure is measured at 3 points as follows:

Freeboard pressure tap - This pressure tap indicates the pressure of any point in the reactor freeboard, as compared to outside atmospheric pressure.

Windbox pressure - During normal operation such as sludge incineration or bed reheating, the windbox pressure should be in the vicinity of 100 to 120 inches of water.

Bed pressure tap - The bed pressure tap centerline is located 12 inches above the surface of the constriction plate. For practical reasons, it is not possible to locate the pipe much lower.

normal pressure tap readings

Due to the pulsations of the fluid bed, it is perfectly normal for the pressure readings to bounce slightly in rhythm with the bed.

freeboard

The freeboard pressure should be approximately 40 inches of water when sludge is being incinerated at the design feed rate of the reactor. When the sludge feed is stopped, the freeboard pressure will decrease to say, 5 to 10 inches of water. This is because the large volume of evaporated water vapor carried by the sludge is no longer present.

If the freeboard pressure is unusually high, it may indicate partial blockage of the exhaust gas ducts or the scrubber. Investigation is required.

The water seal expansion joint has a low flow switch which will deactivate the fluidizing blower and the preheat burner blower upon sensing a low flow to the water seal.

bed depth

The total depth of the fluid bed should be maintained at 60 inches. A fluidized bed of sand resembles a container of boiling water. By coincidence the density of a cubic foot of the fluidized sand-air mixture is nearly the same as the density of a cubic foot of water. Therefore, the pressure reading at the bottom of a fluidized sand bed, 60 inches deep, is approximately the same as if the bed was filled with a stationary "bed" of water also 60 inches deep. For this reason, when the bed pressure tap reads, say 48 inches of water, there is approximately 48 inches of fluidized sand above the tip of the pressure tap pipe within the bed. Since the tip of the pressure tap is normally 12 inches above the bottom of the bed, the total bed depth should be 60 inches of fluidized sand (48 inches plus 12 inches).

scrubber water control

The flow to the quench sprays is manually set with the use of the flow indicator in the water line to the sprays. A solenoid valve in the line opens with the starting of the fluidizing blower or preheat burner blower.

The water make-up to the scrubber recirculation system is accomplished by a liquid level control in the base of the scrubber. The recirculation rate of ash water can best be measured by the pressure drop which should be in the 20 to 35 psig range. The pressure drop can be correlated directly with flow rate.

scrubber high inlet temperature

A temperature switch installed in the scrubber inlet duct warns the operator of high gas temperature by sounding an alarm.

Process Control

combustion

The quantity of fluidizing air injected into the reactor is an important variable. An excessive quantity of air would blow sand and incomplete products of combustion into the flue gases and would result in needless fuel consumption. Insufficient air results in unburned combustibles in the exhaust gases. Fluidized bed systems are typically operated with 20 to 40 percent excess air. In practice, this rate is controlled by measuring the oxygen in the reactor exhaust gases and adjusting the air rate to maintain 4 to 6 percent oxygen.

air requirements

Since the theoretical amount of air is never enough for complete fuel combustion, "excess air" must be added. The extra air is expressed as a percentage of the theoretical air requirement. For example, if a fuel requires 1,000 standard cubic feet of air per minute (SCFM), based on theoretical air requirements and the actual air rate is 1,200 SCFM, the percent excess air is:

$$\frac{(100)(\text{Actual air rate - theoretical})}{\text{Theoretical}} =$$

$$\frac{(1{,}200 - 1{,}000) \times 100}{1{,}000} = 20 \text{ percent excess air}$$

fuel

Auxiliary fuel is used during startup to raise the sand bed to about 1,200°F. As soon as sludge feed to the furnace begins, the auxiliary fuel rate must be adjusted downward to achieve the maximum heat release from the sludge and to avoid wasting fuel. This is done by gradually reducing the fuel feed rate to the minimum that is necessary to maintain bed temperatures in the 1,250 to 1,300°F range.

EMERGENCY OPERATING PROCEDURES

Loss of Power

Upon a momentary or extended loss of power, the preheat burner bed gun and all electrically driven equipment will shut down. Sludge may be stored in the thickener or hauled to a landfill by truck until the power supply is restored.

Loss of Fuel

If the reactor must be operated continuously and the primary fuel supply is interruptible, an auxiliary fuel source should be provided. For instance, LPG can be provided as a standby to an interruptible natural gas supply.

COMMON DESIGN SHORTCOMINGS

Shortcoming	Solution
1. Inadequate dewatering, solids content low.	1a. Add more chemical aids to dewatering device.
	1b. Try varying type of chemical.
	1c. Increase fuel to reactor as temporary measure.
2. No provision for handling sludge during power outage or reactor downtime.	2a. Store sludge in clarifiers (temporarily).
	2b. Haul sludge to landfill.
3. Reactor undersized.	3a. Increase hours of operation.
	3b. Improve dewatering performance.

Shortcoming	Solution
4. Scrubber discharge water piping plugs with scale and ash.	4. Keep pipe short and accessible for cleaning or replacement.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Bed temperature is falling.	1a. Inadequate fuel supply.	1a. Fuel system operation.	1a. Increase fuel feed rate or repair any fuel system malfunctions.
	1b. Excessive rate of sludge feed.	1b. Sludge feed system.	1b. Decrease sludge feed rate.
	1c. Excessive sludge moisture.	1c. Dewatering system.	1c. Improve dewatering system operation (see appropriate section of this manual).
	1d. Excessive air flow.	1d. Oxygen content of exhaust gas should not exceed 6 percent.	1d. Reduce air rate.
2. Low (<4%) oxygen in exhaust gas.	2a. Low air flow.	2a. Air flow rate.	2a. Increase air blower rate.
	2b. Fuel rate too high.	2b. Fuel rate.	2b. Decrease fuel rate.
3. Excessive (>6%) oxygen in exhaust gas.	3a. Sludge feed rate too low.	3a. Sludge feed rate.	3a. Increase sludge feed rate and adjust fuel rate to maintain steady bed temperature.
4. Erratic bed depth readings on control panel.	4a. Bed pressure taps plugged with solids.		4a. Tap a metal rod into pressure tap pipe when reactor is not in operation.
			4b. Apply compressed air to pressure tap while the reactor is in operation after reviewing manufacturer's safety instructions.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
5. Preheat burner fails and alarm sounds.	5a. Pilot flame not receiving fuel.	5a. Fuel pressure and valves in fuel line.	5a. Open appropriate valves and establish fuel supply.
	5b. Pilot flame not receiving spark.	5b. Remove spark plug and check for spark; check transformer.	5b. Replace defective part.
	5c. Pressure regulators defective.		5c. Disassemble and thoroughly clean regulators.
	5d. Pilot flame ignites but flame scanner malfunctions.	5d. Scanner operation.	5d. Clean sight glass on scanner; replace defective scanner.
6. Bed temperature too high.	6a. Fuel feed rate too high through bed guns.		6a. Decrease fuel flow rate through bed guns.
	6b. Bed guns have been turned off but temperature still too high due to greasy solids or increased heat value of sludge.		6b. Raise air flow rate or decrease sludge feed rate.
7. Bed temperature reads off scale.	7a. Thermocouple burned out.	7a. Check the entire control system.	7a. Repair as necessary.
	7b. Controller malfunction.		
8. Scrubber inlet shows high temperature.	8a. No water flowing in scrubber.	8a. Water pressure and valve positions.	8a. Open valves.
	8b. Spray nozzles plugged.	8b. Check nozzles by removing and connecting them to external water source.	8b. Clean nozzles and strainers.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
	8c. Ash water not recirculating.	8c. Pump operation and scrubber pluggage.	8c. Return pump to service or remove scrubber pluggage.
9. Reactor sludge feed pump fails.	9a. Bed temperature interlocks may have shut pump down.	9a. Bed temperature.	9a. (See items 1 and 6).
	9b. Pump is blocked.	9b. Sludge too concentrated.	9b. Dilute feed sludge with water.
10. Poor bed fluidization.	10a. During shutdowns, sand has leaked through support plate.		10a. Once per month, clean windbox.

MAINTENANCE CONSIDERATIONS

addition of make-up sand

Sand from the reactor bed is gradually lost through the exhaust as individual sand particles are gradually worn into finer and finer particles. When it has been determined that the bed level is getting low, proceed as follows:

1. Bed temperature should be at least 1,400°F before any sand is added to the reactor bed. This is to avoid cooling the bed below 1,150°F, and being forced to light the preheat burner.

2. Be sure that the fluidizing blower is completely stopped.

3. Remove the blind flange on the sand feed nozzle. Attach sand feed chute.

4. Add sand in 10 bag batches. If more than 10 bags are required, replace the blind flange on the same feed nozzle and reheat the bed to 1,400°F before adding second 10 bag batch.

reactor windbox

There may be slight leakage of sand down into the windbox. About once a month (when the reactor is not operating), open the windbox manhole and rake out any accumulation.

bed fuel guns

Occasionally a carbon deposit may form near the tip of the fuel burner. If this happens, fuel flow to the bed will be restricted. When the reactor is shutdown, clean the burner. If available, a slight flow of compressed air will aid inserting the gun back in the bed.

From time to time, check that the nut on the packing gland is just tight enough to prevent loss of cooling air.

bed pressure tap

At times this pressure tap pipe may become partially plugged. Refer to manufacturer's manual for cleaning instructions.

gaskets

Keep gasketed surfaces on the reactor tight to avoid a fly ash nuisance.

SAFETY CONSIDERATIONS

Safety measures should include the following:

1. No smoking should be allowed around the fuel lines or when checking the system for leaks.

2. Protective clothing should be worn when repairing or

lighting the furnace.

3. Protective goggles should be used when lighting the furnace.

REFERENCE MATERIAL

References

1. Standard Methods For The Examination of Water and Wastewater.
American Public Health Association
1015 Eighteenth Street, N.W.
Washington, D.C. 20036

2. Dorr-Oliver FS Disposal System Operating Instructions.

3. Copeland Systems

Glossary of Terms and Sample Calculations

1. Excess air is the amount of air required beyond the theoretical air requirements for complete combustion. This parameter is expressed as a percentage of the theoretical air required.

Sample calculation for excess air: Assume 1,200 SCFM actual, and 1,000 SCFM theoretical

Excess air =

$$\frac{(\text{actual air rate} - \text{theoretical air rate}) \times 100}{\text{theoretical air rate}}$$

$$= \frac{(1{,}200 \text{ to } 1{,}000) \times 100}{1{,}000} = 20\%$$

2. Sludge loading rate is the weight of wet sludge fed to the reactor per square foot of reactor bed area per hour (lb/sq ft/hr).

Sample loading rate: Assume 20 foot reactor, 20 percent feed sludge moisture content and 440 pounds dry sludge per hour

$$\text{Loading rate} = \frac{(\text{lb dry sludge/hr})(100)}{(\%\ \text{moisture content})(\text{area})}$$

$$= \frac{440 \times 100}{20\% \times \frac{3.14\ (20)^2}{4}}$$

$$= 7.01 \text{ lb/sq ft/hr}$$

3. Solids concentration is the weight of dry solids per unit weight of wet sludge. It is calculated as follows:

   Assume 120 lb wet sludge with 25 lb of dry solids.

$$\text{Concentration} = \frac{\text{weight of dry sludge solids} \times 100}{\text{weight of wet sludge}}$$

$$= \frac{25 \times 100}{120}$$

$$= 20.8\%$$

4. Moisture content is the amount of water per unit weight of sludge. The moisture content is expressed as a percentage of the total weight of the wet sludge. This parameter is equal to 100 minus the solids concentration or can be computed as follows:

   Same assumptions as paragraph 3.

   Moisture content =

$$\frac{(\text{weight of wet solids} - \text{weight of dry solids}) \times 100}{\text{weight of wet solids}}$$

$$= \frac{120 \text{ to } 25}{120} \times 100$$

$$= 79.2\%$$

XVII

COMPOSTING

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PROCESS DESCRIPTION

process Raw wastewater sludge (and sometimes digested sludge) requires processing before disposal or use in order to reduce the possibility of problems with odors, flies, disease, and other nuisances. This processing is commonly called stabilization. Composting is one means of stabilizing raw or digested sludge through biological action (bacterial organisms). Heat is produced during the composting process and is generally sufficient to produce temperatures above 55° to 60°C within the compost. These temperatures are high enough to kill most pathogenic organisms, therefore, composting is capable of reducing disease-producing organisms to very low levels.

methods Two methods have been used for composting wastewater sludge: windrow and forced air static pile. Various contained composting methods have been used for solid waste, but have not been used for wastewater sludge. Generally, the Windrow method, shown in Figure XVII-1 (see following page) is used with digested sludge and the forced air static pile method, shown in Figure XVII-2 (see following page) is used with either raw or digested sludges.

equipment The equipment and methods used are somewhat different for each composting method and each is covered in this manual. The type and size of equipment required also depends on the quantity of sludge to be composted, however, certain minimum sized equipment is required for any sized operation. Most composting operations use mobile type equipment, but it is also possible to use fixed type equipment for certain operations. The type of equipment required is shown in Table XVII-1 (see following page).

A schematic of the two typical composting operations is shown in Figure XVII-3 (see following page). These steps are described in detail under NORMAL OPERATING PROCEDURES.

The descriptions in this manual are typical for processing an annual sludge input up to approximately 3,500 dry tons per year.

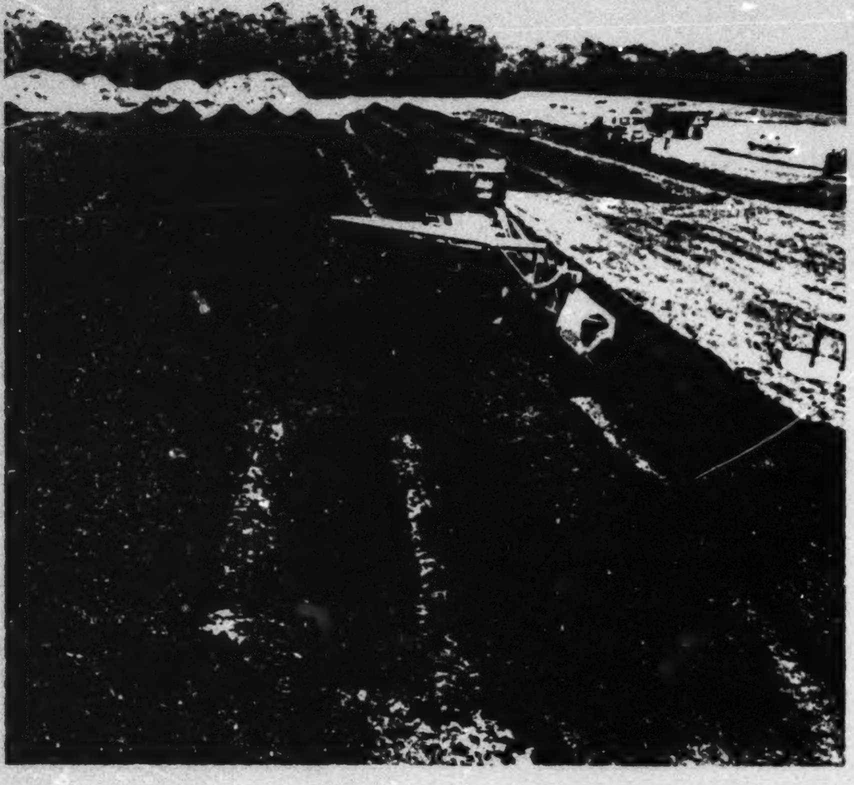
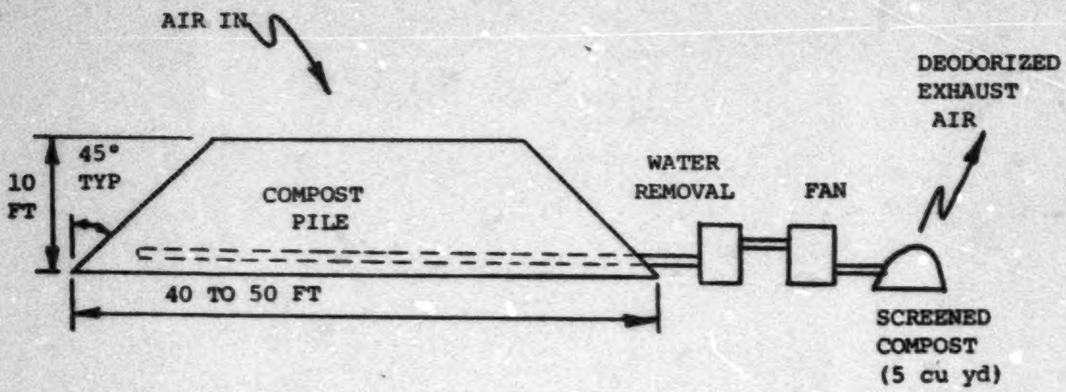
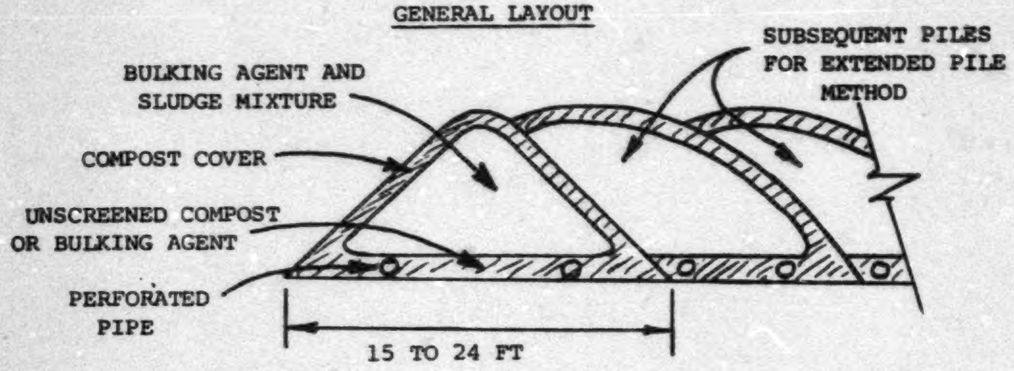


Figure XVII-1. Windrow composting at Beltsville, Maryland.


AIR IN
DEODORIZED
EXHAUST
AIR
45°
TYP
10
FT
COMPOST
PILE
WATER
REMOVAL
FAN
40 TO 50 FT
SCREENED
COMPOST
(5 cu yd)

GENERAL LAYOUT


SUBSEQUENT PILES
FOR EXTENDED PILE
METHOD
BULKING AGENT AND
SLUDGE MIXTURE
COMPOST COVER
UNSCREENED COMPOST
OR BULKING AGENT
PERFORATED
PIPE
15 TO 24 FT

CROSS SECTION

Figure XVII-2. Typical forced aeration compost pile.

TABLE XVII-1. COMPOSTING EQUIPMENT

Windrow	Forced air static pile
Specialized windrow turner	Rubber tired front loader, 4 cu yd
Dump truck (*)	Dump truck (*)
Rubber tired front loader, 4 cu yd	Aeration blower assemblies and pipe
Drum screen	Drum screen
	Composting machine (**)

* Requirement will depend on site and operation

** May be helpful for mixing on larger applications

sidestreams

Process sidestreams consist of storm runoff water from the site and excess water released from the piles during the composting and curing processes. The site should be designed so this water is collected, normally in a lagoon. In some cases this runoff can be placed directly into a sewer if it will not overload its treatment plant hydraulically or biologically. The collected runoff should be disposed of in a manner acceptable to local conditions. One means of disposal is to spread it on adjacent land at a controlled rate which may or may not require some degree of treatment.

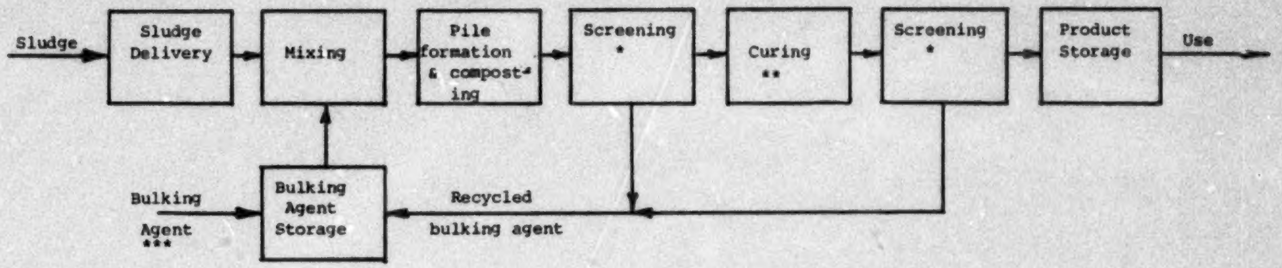
TYPICAL DESIGN CRITERIA & PERFORMANCE

Loading Rates

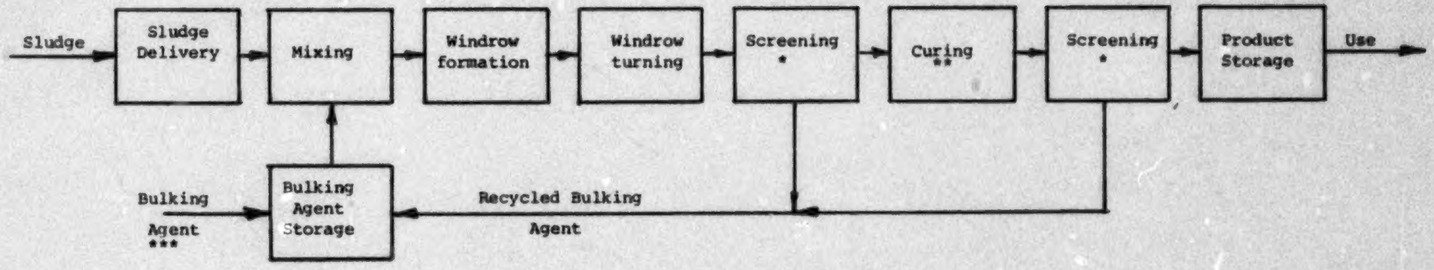
Dewatered sludge - 20 to 25 percent solids (1 dry ton solids is equal to approximately 7 cubic yards of dewatered sludge)

Sludge - Bulking agent Mix ratio - 2.5 to 3.0 parts bulking agent to 1 part dewatered sludge by volume

Bulking agent - Requires 17 to 21 cubic yard per dry ton of sludge. Typical bulking agents:
  wood chips
  bark chips
  shreaded tires
  compost


Sludge
Sludge Delivery
Mixing
Pile formation & composting
Screening *
Curing **
Screening *
Product Storage
Use
Bulking Agent ***
Bulking Agent Storage
Recycled bulking agent

Forced Air Static Pile Composting


Sludge
Sludge Delivery
Mixing
Windrow formation
Windrow turning
Screening *
Curing **
Screening *
Product Storage
Use
Bulking Agent ***
Bulking Agent Storage
Recycled Bulking Agent

Windrow Composting

Figure XVII-3. Composting operations.

* Screening will normally be accomplished either prior to or just after the curing step.

** The purpose of curing is provide storage time for the compost at elevated temperature for additional pathogen kill and stabilization.

*** The purpose of the bulking agent is to add porosity to the sludge so air can pass through more readily.

Composting period - 14 to 21 days

Curing period - 30 days

Expected Performance

Compost production
  Unscreened - 26 cubic yard per dry ton sludge
  Screened (¼ inch screen) - 10 to 12 cubic yard per dry ton sludge
  Minimum composting temperature - 55 to 60°C - Forced air static pile; 50 to 55°C - Windrow

Finished compost
  Moisture content - 40 to 50 percent
  Volatile solids - 40 percent

Bulking agent recovery - Variable depending on type of agent, degree of screening, but in range of 60 to 80 percent following screening.

Sidestream (Runoff water)

Data are not available on runoff water characteristics except that the quantity may vary from 6 to 20 gallons per day per pile containing 50 cubic yards of sludge during dry weather.

STAFFING REQUIREMENTS

Staffing includes personnel for materials handling at the site, mixing, composting, monitoring and screening. It does not include hauling materials to or from the composting site. The equipment operators should be competent on heavy equipment such as front loaders and trucks. Typical staffing for two sized operations is shown in Table XVII-3 (see following pages). This table is based on two actual operations.

TABLE XVII-3. COMPOSTING LABOR REQUIREMENTS

	Labor, hr/yr	
	350 dry tons sludge annually (*)	3,000 dry tons sludge annually(**)
Administration & supervision	720	1,800
Equipment operator	1,260	7,200
Laborer	360	1,800

(*) Based on sludge delivery to site once a week

(**) Based on sludge delivery to site five days a week

MONITORING

	SIZE OF OPERATION, DRY TONS SLUDGE/YR	TEST FREQUENCY	LOCATION OF TEST OR SAMPLE POINT	FREQUENCY AND TYPE OF SAMPLE	TEST PURPOSE
TEMPERATURE	ALL	D, 2W*	W	–	P
OXYGEN	ALL	D, 2W*	W	–	P
TOTAL COLIFORM FECAL COLIFORM SALMONELLA	ALL	0	C, S	G	H
MOISTURE	ALL	0	W, S, B	G	P
NITROGEN	ALL	0	D	G	H

A. TEST FREQUENCY

D = DAILY
2/W = TWICE/WEEK
O = ONCE/PROCESS CYCLE

B. LOCATION

W = WINDROW OR COMPOST PILE
C = CURING PILE
S = STORAGE (PRIOR TO SCREENING)
B = BULKING AGENT (PRIOR TO USE)
D = FINISHED COMPOST PRIOR TO DISTRIBUTION

C. FREQUENCY & TYPE OF SAMPLING

G = GRAB

D. REASON FOR TEST

H = HISTORICAL DATA
P = PROCESS CONTROL

*Daily until temperature reaches 50 to 55° C, then twice/week, test for temperature and oxygen concurrently.

Sensory Observations

1. Odor
2. Visual
    a. Steam (heat)
    b. Color (moisture)
    c. Uniformity

NORMAL OPERATING PROCEDURES

Operating procedures will vary from operation to operation depending on size, type of bulking agent, and personnel and equipment. These procedures are general and should be applicable to many operations or easily adaptable to specific cases. Some of the operations are common to both windrow and forced air static pile (FASP) composting. The procedure is outlined for the windrow method first. The forced air static pile (FASP) is then covered using referenced back to the windrow method for common steps.

Windrow Composting

1. Sludge Mixing

a. Lay down a base or bases of bulking agent in the mixing area in preparation for sludge delivery. This base should be 18 to 24 inches deep and the volume related to the volume of each load of sludge to be delivered and the desired mixing ration. For example, if sludge is delivered in 7 cubic yard loads and the desired mix ratio is 3 parts bulking agent to one part sludge, each bulking agent base should contain 21 cubic yards. This would be a pile 2 feet deep and approximately 10 feet by 28 feet for forced air static pile composting. For windrow composting the base should be laid in strips approximately 12 inches deep and 8 to 15 feet wide depending on the type of composter.

b. The sludge should be dumped on top of the prepared base of bulking agent. The sludge is then back dragged over the bulking agent to form a reasonably uniform layer. Another possibility is to place only half the required bulking agent down before dumping the sludge and then place the other half of the bulking agent over the top of the spread sludge to form a sandwich.

c. The sludge and bulking agent is thoroughly mixed to form a homogeneous mixture. This mixing can be performed with a front loader, a combination of front loader and grader, a composting machine, or other equipment that can provide a relatively uniform mixture.

2. Windrow Formation

The mixed sludge and bulking agent is formed into windrows with a triangular cross section. The windrow should be a convenient size for the type of composting machine to be used but, typically, the windrow will be 6 to 8 feet wide and 5 to 6 feet high.

3. Composting

a. The windrow should be turned daily except when it is raining. The windrow should not be turned or moved during rainy weather.

b. The interior temperature should increase steadily to above 50°C within a few days. The temperature should remain above 50°C for several days.

c. The turning cycle should continue for two to three weeks and then the row should be flattened for further drying.

4. Windrow Removal

a. The compost process requires approximately 21 days.

b. At the end of the compost period the compost pile or windrow should be torn down and placed in curing. This can be done with a front loader and the forced aeration pipe may or may not be salvaged as desired.

c. The entire pile contents are placed in the curing pile.

d. When the extended pile method is used only the portion of the pile is removed corresponding to 21 days of composting.

5. Curing

The compost should remain in the curing pile for at least 30 days prior to distribution.

6. Screening

a. Screening is desirable, but not always needed. The reason for screening is to remove the coarser bulking agent from the compost to produce a finer product and/or so the screened out bulking agent can be reused. Wood product bulking agent draws nitrogen available for fertilization purposes.

b. If screening is used, it can be accomplished either as the compost pile is torn down (prior to curing) or after curing. For best screening the moisture content should be below 40 or 50 percent.

c. Generally, screening is difficult to carry out in freezing weather or in the open during rain.

Forced Air Static Pile Composting

1. Aeration Pipe

a. Lay out parallel sections of perforated pipe (4 inches plastic drainage type, 4 inches schedule 40 steel, or similar) with each section approximately 7 feet apart.

b. Plug the ends with cans or similar closure.

c. The other ends are connected with "Y" fittings to a common solid pipe leading out of the pile.

2. Blower Equipment

a. Connect the aeration pipe to the suction of the blower. Provide some means of removing water from the suction pipe either by making a hole at the lowest part of the pipe or by installing a moisture trap. This is extremely important because water is collected in the aeration piping and must be removed. For locations which experience periods of below freezing weather, water removal is very important to prevent moisture from freezing in the blower during the off cycle and burning out the motor on attempted restart.

b. Connect a pipe to the blower discharge and cover the other end with a pile of bulking agent or compost (5 cubic yards) for deodorization.

3. Base for Pile

Lay down a 6-to 12-inch thick layer of bulking agent over the aeration piping with the outside dimensions the same as the base of the proposed finished pile (Some operations omit this step and place the sludge bulking agent mixture over the piping.).

Caution: The moisture content of the bulking agent is critical to good composting performance. Bulking agent containing more than 40 or 50 percent moisture should not be used. Also, moisture will be picked up if mixing is carried out during precipitation. If it is raining it is best to postpone pile construction to another day. If it must be done, the bulking agent should be spread just before the sludge arrives, mixing should proceed as fast as possible, and the mixture placed on the pile immediately.

4. Sludge Mixing

This step is the same as for step 1 of Windrow Composting.

5. Pile Formation

a. The mixture is piled on the composting pile over the aeration piping and base. The pile should be a convenient height of 7 to 10 feet and should extend from the "Y" in the aeration piping to about 5 feet beyond the capped ends. The sludge should be mixed and piled as soon as it is delivered to the site to make best use of labor and equipment.

b. The compost pile is then covered with 1 to 2 feet of previously composted material or bulking agent to provide insulation and help in odor control. The depth of cover required is somewhat dependent on ambient air temperature. Generally, more cover should be used during extreme cold.

6. Blower Operation

Check blower timer settings and activate blower. Check for proper operation.

7. Extended Pile Modification

If the extended pile configuration is to be used the procedures for pile formation are the same as for the individual pile except as follows:

a. Instead of forming new piles each time sludge is mixed, the new mixture should be piled against one side of the previous pile.

b. It may be that less cover is needed on the side that is to be extended especially if sludge is added each day.

8. Composting

a. Operations should be monitored as outlined in the monitoring section and as developed for the specific application.

b. The interior pile temperature should increase steadily to at least 60°C within a few days. See Troubleshooting Guide if the temperature does not come up.

c. Check all equipment at least once a day and be sure that blower is operating properly.

d. The blower operating cycle should be adjusted based on interior oxygen levels. This is not a precise method for adjusting timer settings, but is a guideline method. Ideally, the oxygen level should be 5 to 15 percent. If the oxygen is around 5 percent the blower "on" time should be increased and if the oxygen is above 15 percent, the "on" time should be decreased. Some operations have found interior temperature measurements to be a more reliable indicator of composting operation because of the difficulty of sampling interior oxygen levels reliably.

e. During the composting period the pile temperature should rise rapidly to 60°C or above and should remain at that level for several days. The temperature should rise rapidly to 60°C or above and should remain at that level for several days. The temperature may drop during the latter part of the cycle.

9. Pile Removal

This step is the same as for step 4 of Windrow Composting.

10. Curing

This step is the same as for step 5 of Windrow Composting.

11. Screening

This step is the same as for step 6 of Windrow Composting.

CONTROL CONSIDERATIONS

Physical Control

There is no permanent process instrumentation required. Process monitoring can be performed with the following portable instrumentation:

1. Portable oxygen analyzer with a probe.
2. Probe type temperature indicator.

Process control can be accomplished by adjustments to the aeration blower timer for the forced aeration static pile method or in modifications to the turning schedule with the Windrow method.

Process Control

monitoring

Typically, the composting process can be monitored based on temperature, oxygen, and moisture analysis.

moisture

Measurement of moisture content of bulking agent, compost at the end of the composting period, and spot checks of the cured compost will provide useful information. Typically, wood or wood product bulking agent should not be used if the moisture content is above 45 to 55 percent. Compost at the end of the composting period should have a moisture content of 40 to 50 percent, and cured compost should have a moisture content less than 40 to 45 percent for best screening. The moisture content of screened compost is not too important. Moisture content can be determined according to the procedure for determination of sludge residue in Standard Methods.

nutrients and pathogens

Pathogen and nutrient monitoring may be practiced as a general check on process performance but, because of the complexity of the test procedures will not normally be economical or practical as a basis for day-to-day process control. This is a very specialized procedure and must be performed by a properly equipped laboratory.

Some sensory observations are helpful in carrying out composting operations.

1. Visual observations are helpful in carrying out the sludge-bulking agent mixing. The mixed material should be relatively homogeneous without large lumps of sludge.

2. Visual observations can help to detect materials (especially bulking agent) with too high a moisture content. These observations should be followed up with tests.

sensory observations

3. Noticeable odors are a good indication of problems in the composting process. If odors are noted, a problem probably exists and the trouble should be isolated.

4. Personnel should watch for excessive water buildup in aeration piping and during freezing weather watch for freezing of aeration piping or freezing of blowers due to ice accumulation.

temperature

Temperature is the most important indicator for the first several days of operation. The interior temperature should increase rapidly and reach 50°C for Windrows and 60°C for forced aeration static piles within 3 or 4 days. Typically, the temperature should remain above 50°C to 60°C for a period of time and may drop a little toward the end of the composting cycle. It is recommended that temperature readings be taken once a day until the pile temperature reaches 50°C to 60°C and then every two to three days thereafter. Temperature readings should be taken at three or four locations within the pile; one near the center, one near the outside (just under the cover), and one at either end about 2 feet in from the surface and at several locations within the windrow. All readings should be recorded on permanent log sheets. It is also helpful to plot the temperature readings to give a graphic indication of performance.

oxygen

Oxygen analysis should be made for each temperature reading at the same time and location. Theoretically, the oxygen readings serve as a basis for changing the blower timer settings and for evaluation of windrow turning. Interior oxygen levels should be maintained between 5 to 15 percent. If the oxygen falls to 5 or below the blower "on" time should be increased and if it rises above 15 percent the blower "on" time should be decreased. In practice, this control may not work out as a direct relationship between oxygen and timer setting, but some modification of this ideal control should provide an adequate basis for timer changes. In the windrow process, if the oxygen level falls below 5 percent the windrow should be turned more often.

In some cases, if too much aeration is being provided, it may show up as a decrease in pile temperature and the aeration should be modified.

One static pile forced air installation found that reversing the blower connections (blowing air into the pile) when pile temperatures started dropping part way through the composting period helped to maintain temperatures for a longer period.

Another static pile forced air installation located in a very cold climate found that two modifications helped during winter operations:

1. Warm compost taken directly from a finished compost pile could be used as bulking agent for mixing with new sludge to form a new pile. They were able to reuse compost as a bulking agent for two or three cycles before placing it into curing. This decreased the bulking agent requirements, but more importantly, provided a warm material to help accelerate the composting action in a new pile. This may be helpful with both forced air static pile and windrow methods.

2. Exhaust air from an existing hot forced aeration composting pile is blown into a new pile for the first few days to help accelerate the composting action. This should only be done for the first few days or excessive moisture will build-up in the new pile.

EMERGENCY OPERATING PROCEDURES

Composting Site Shutdown

Sludge should not be delivered to the site if it can not be mixed and formed into compost piles or windrows either due to weather, labor, or equipment problems. The best procedure is to store it at the plant. Some provision must be available for short term sludge storage or alternate means of disposal because problems will develop from time to time.

Odor Generation

The best procedure is to carry out careful operations so odors are not generated. If unusual odors are detected the cause of the problem should be determined and then resolved. As a temporary measure, chemicals can be used to mask the odor. Some odor control chemicals are listed in the February 1977 issue of Water and Wastes Engineering magazine.

COMMON DESIGN SHORTCOMINGS

Shortcoming	Solution
1. Water accumulates in aeration piping to blower and in very cold weather blower freezes during "off" cycle. (FASP)	1. Install a moisture trap in the suction piping. If blower still freezes, the blower housing should be heated.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Compost pile does not reach 50°C to 60°C in a few days after construction.	1a. Poor mixing of sludge & bulking agent.	1a. Pile oxygen.	1a. If oxygen levels are above 15%, reduce operating time of blower. (FASP)
	1b. Bulking agent too wet.	1b. Moisture content of bulking agent.	1b. Pipe hot exhaust air from an adjacent pile into this pile to try to bring it up to temperature. (FASP)
	1c. Too much aeration.	1c. Depth and uniformity of pile cover (insulation). (FASP)	1c. If the pile does not come up to temperature within a couple of days after taking these steps, the pile should be torn down, remixed, and reconstructed. If the bulking agent is too wet (above 45 to 55% moisture) it must be dried or, perhaps, drier bulking agent can be found deeper within the bulking agent storage pile.
2. Temperature does not remain above 50°C to 60°C more than a day or two, then drops.	2a. Poor mixing of sludge and bulking agent.	2a. Pile temperatures.	2a. Adjust blower cycle to maintain oxygen between 5 and 15%. (FASP)
	2b. Bulking agent too wet.	2b. Pile oxygen.	2b. Pipe hot exhaust air from an adjacent pile into this pile to try to maintain it at temperature. This should only be done for a few days at a time because of moisture accumulation. (FASP)
	2c. Improper aeration. (FASP)	2c. Moisture content of bulking agent.	2c. If temperature does not come back up it probably isn't serious enough to justify remixing, but steps should be taken to correct the problems for the next composting cycle.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
		2d. Aeration blower operation. (FASP) 2e. Depth and uniformity of pile cover (insulation). (FASP)	
3. Odors are emitted from a composting pile.	3a. Poor mixing of sludge and bulking agent. 3b. Poor air distribution in pile. (FASP)	3a. Pile temperatures. 3b. Pile oxygen.	3a. Check blower for proper operation and that aeration pipes are not plugged. (FASP) 3b. Generally the odors develop from anaerobic conditions in the pile resulting from lack of air. Probably the best procedure is to increase the blower "on" cycle or run it continuously until the odors disappear (FASP), or turn the windrow more often.
4. Blower does not operate. (FASP)	4a. Timer failure. 4b. Power failure. 4c. Motor failure. 4d. Fan is "frozen" from corrosion or ice and will not turn.	4a. Power supply. 4b. Turn fan by hand. 4c. Inspect timer or try a new one.	4a. Check each probable cause until trouble is found.

MAINTENANCE CONSIDERATIONS

Regular maintenance as outlined by the manufacturers should be performed on all equipment. A protected area should be provided for equipment service during inclement weather.

There are no special maintenance considerations related to a composting operation other than the blowers and timers. Spare units should be kept in stock for these items so that inoperative units can be replaced.

SAFETY CONSIDERATIONS

The safety considerations are standard for the use of the mobile and/or fixed equipment. The operations require that the equipment (especially the front loader) be moved around the site rapidly with many changes of direction. Therefore, it is well to have the operating areas separated from public areas and the access limited.

The site can get very slippery and appropriate caution should be exercised when operating the equipment.

REFERENCE MATERIAL

References

1. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, 1015 Eighteenth Street, N.W., Washington, D.C. 20036.
2. Epstein, E., et al. A Forced Aeration System for Composting Wastewater Sludge. Journal WPCF, Vol. 48, No. 4, April 1976, page 688.

Glossary of Terms and Sample Calculations

1. Volatile solids are determined from total residue, and is the ratio of weight lost after heating to 600°C to the weight of total residue prior to heating to 600°C. Volatile content, expressed in percent, generally, is assumed to indicate approximate organic content. Test procedures are outlined in Standard Methods.
2. Temperature can be measured using one of many types of portable instruments. In some cases a simple dial thermometer with an extended probe 3 to 4 feet long has proven satisfactory. In any case the probe must be 3 to 4 feet long and strong enough to be pushed into the pile against large pieces of bulking agent. For reference the following conversion may be helpful:

°C	°F
50	122
55	131
60	140

3. Oxygen can be measured with a portable oxygen analyzer. The instrument should have a probe 3 to 4 feet long that can be inserted into the compost. Typically, these instruments are calibrated to air and are relatively easy to operate.

XVIII

LAND APPLICATION

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PROCESS DESCRIPTION

process

The land application operation and maintenance information in this chapter applies to controlled application of liquid wastewater sludge to cropland by subsurface injection or surface spreading. Injection can be accomplished by truck or tractor mounted injectors. Tank trucks are normally used for surface spreading. Dewatered sludge can also be applied, but this is not as common as liquid application and will not be covered. This manual is tailored to use of sludge for crop production, the farm operation (beyond application) being accomplished by the farmer rather than the sludge producing agency, and transport of the sludge to the farm by truck. Obviously, there are many field variations to this assumed operation, but certain limits must be established to limit the scope of this manual.

operation

Sludge is digested, concentrated to 6 to 8 percent solids, and then pumped into transfer trucks which haul sludge to the land application site. Sludge is then transferred to another specialized truck for application. In some cases, especially smaller operations, the transfer truck may be used for application.

transport

Sludge transportation can be accomplished by truck, rail, barge, or pipeline. Barge transport is limited to areas with navigable waterways and large volumes of sludge to be moved. Pipeline transport is limited to large volumes of dilute liquid sludge (less than 4 percent solids). Local conditions will normally have a significant effect on selection of a specific or a combination of transport modes. For example, if there are several application locations or farms, the sludge may be transported to a central location and then transferred by another mode to the several application locations.

spreading

Variations in the characteristics of sludge application equipment are related to local conditions and sludge solids content. Dewatered sludge (greater than 10 percent solids concentration) is not practical for injection and would normally be spread on the surface. Liquid sludge can be spread on the surface by special irrigation equipment or tanker truck. Subsurface injection of sludge can be accomplished by tank truck or tractor mounted injectors. Tractor mounted injectors require a sludge feed from a close following tank trailer or from a hose connected to a storage system. Ridge and furrow or flooding methods of application are not recommended unless there is a means of covering the applied sludge because nuisances may result.

Typical injector trucks are shown in Figure XVIII-1. Transfer of sludge from the highway truck to the application truck is shown in Figure XVIII-2.

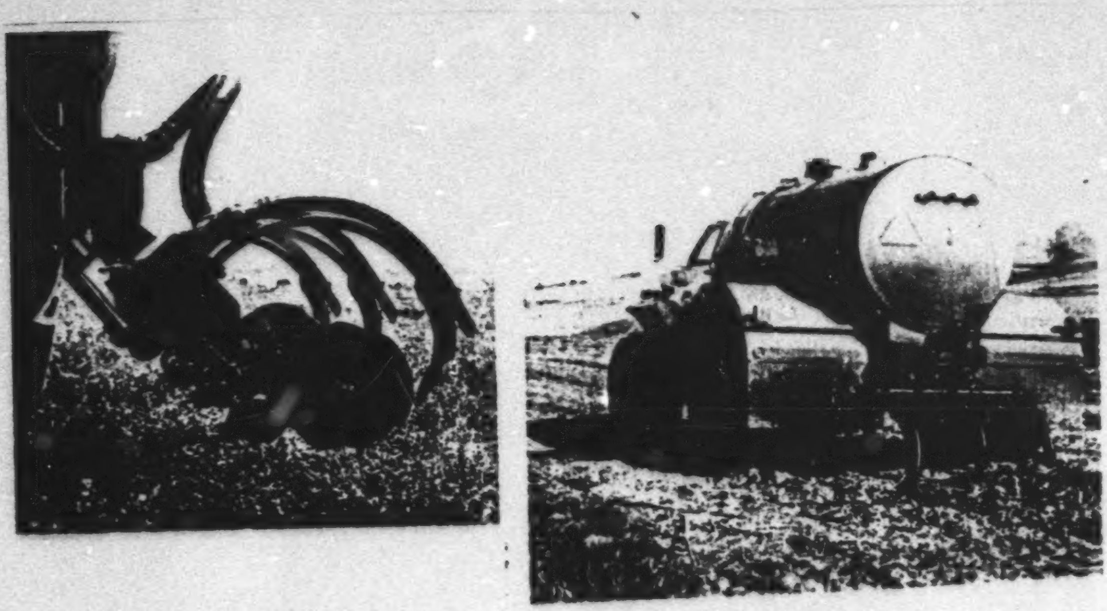

Figure XVIII-1. Injector truck. (Courtesy of Big Wheels, Inc.)

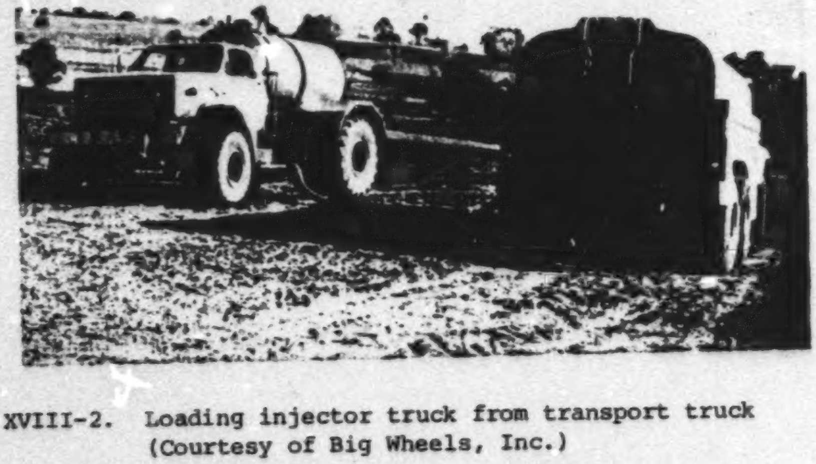

Figure XVIII-2. Loading injector truck from transport truck (Courtesy of Big Wheels, Inc.)

sidestreams

There are no sidestreams from this process as long as application rates are not excessive. If the application rates or methods are not controlled, the sludge may pond on the surface and runoff thereby creating an unwanted sidestream.

TYPICAL DESIGN CRITERIA AND PERFORMANCE

Note: All reference to sludge weight is on a dry solids basis.

application rate determination

The loading rate or application rate is a function of the sludge and soil characteristics and crop nutrient requirements. Sludge and soil characteristics vary even for a given situation and crop requirements vary widely. For this reason and for changing nutrient requirements based on crop rotation, there is no one general application rate.

The sludge application rate is primarily based on the sludge nitrogen content and the nitrogen requirements of the crop. Nitrogen is present in aerobically digested sludge in the organic, ammonium, and nitrate forms. The nitrate form is not present in anaerobically digested sludge. Nitrogen is available for immediate plant use in the ammonium (NH_4^+) or nitrate (NO_3^-) forms. The availability of organic nitrogen to the crop depends on the mineralization rate and will normally be available over a period of several years.

Usually, the application rate is first determined based on nitrogen requirements and this rate is then checked for excessive heavy metals or phosphorus accumulation. The critical heavy metals are lead, zinc, copper, nickel, and cadmium.

The procedure for determining the application rate is as follows:

1. Determine the crop nitrogen requirement from Table XVIII-1 (see following page).

2. Calculate sludge application rate to meet the nitrogen requirement. (All sludge weight based on dry solids.)

    a. Available N in sludge:
    lb available N/ton of sludge =
    (lb NH_4-N/ton) + (lb NO_3-N/ton) +
    (lb organic N/ton x mineralization rate - Table XVIII-2) (see following page)

    b. Residual nitrogen in soil (after first year of application). The residual nitrogen can be determined from Table XVIII-2.

TABLE XVIII-1. APPROXIMATE UTILIZATION OF NUTRIENTS BY SELECTED CROPS*

Plant	Yield, per acre	Nitrogen, lb/acre	P_2O_5, lb/acre	K_2O, lb/acre
Alfalfa**	8 tons	370	80	480
Orchard grass	6 tons	300	100	375
Clover grass	6 tons	300	90	360
Corn (grain)	180 bu	240	44	199
Sorghum (grain)	8,000 lb	120	60	30
(stover)	8,000 lb	130	30	170
Corn silage	32 tons	240	100	300
Oats (grain)	100 bu	80	25	20
(straw)		35	15	125
Soybeans (grain)**	60 bu	242	49	87
(straw)	7,000 lb	84	16	58
Wheat (grain)	80 bu	144	44	27
(straw)	6,000 lb	42	10	135
Barley (grain)	100 bu	110	40	35
(straw)		40	15	115

*Better Crops With Plant Food, Copyright 1972 by the Potash Institute of North America.

**These numbers include a credit of 80 lb N/acre for alfalfa and 10 lb N/acre for soybeans for nitrogen fixation.

TABLE XIII-2. MINERALIZATION OF SLUDGE ORGANIC NITROGEN

Years after sludge application	Mineralization rate, %	Annual nitrogen available during yr, lb N/ton sludge								
		% Organic nitrogen in sludge, % by weight								
		2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
1	15	6.0	7.5	9.0	10.5	12.0	13.5	15.0	16.5	18.0
2	10	3.4	4.2	5.1	6.0	5.8	7.6	8.5	9.4	10.2
3	5	1.5	1.9	2.3	2.7	3.1	3.4	3.8	4.2	4.6
4	5	1.5	1.8	2.2	2.5	2.9	3.3	3.6	4.0	4.4
5	5	1.4	1.7	2.1	2.4	2.8	3.1	3.4	3.8	4.1

c. Annual application rate:

$$\text{Tons sludge/acre} = \frac{\text{(crop N requirement)} - \text{(residual N)}}{\text{lb available N/ton sludge}}$$

3. Calculate the maximum allowable sludge application rate. This determination is for the total accumulated heavy metals rather than the annual application. The total

metals that can be applied are shown in Table XVIII-3. Table XVIII-3 is valid provided the soil pH does not fall below 6-5.

TABLE XVIII-3. MAXIMUM ALLOWABLE METALS APPLICATION ON AGRICULTURAL LAND

Metal	Soil cation exchange capacity (meq/100 g) Maximum applied metal (lb/acre) 0-5	5-15	>15
Lead (Pb)	500	1,000	2,000
Zinc (Zn)	250	500	1,000
Copper (Cu)	125	250	500
Nickel (Ni)	50	100	200
Cadmium (Cd)	5	10	20

Using the information from Table XVIII-3, the maximum total sludge application rate is the lowest of the following five computations:

$$\text{Pb: Tons sludge/acre} = \frac{\text{lb Pb/acre}}{\text{ppm Pb} \times .002}$$

$$\text{Zn: Tons sludge/acre} = \frac{\text{lb Zn/acre}}{\text{ppm Zn} \times .002}$$

$$\text{Cu: Tons sludge/acre} = \frac{\text{lb Cu/acre}}{\text{ppm Cu} \times .002}$$

$$\text{Ni: Tons sludge/acre} = \frac{\text{lb Ni/acre}}{\text{ppm Ni} \times .002}$$

$$\text{Cd: Tons sludge/acre} = \frac{\text{lb Cd/acre}}{\text{ppm Cd} \times .002}$$

4. Phosphorus Balance
Tons of sludge/acre x lb P/ton sludge - lb P required/acre = excess lb P/acre (or if negative, the lb/acre P needed).

After five years the phosphorus level in the soil should be determined and sludge application be reduced or ceased if the phosphorus content in the soil, as determined by the Olsen Bicarbonate Test, exceeds 400 pounds per acre.

5. Potassium required
lb K required/acre - tons of sludge/acre x lb K/ton

sludge = lb K/acre needed. There is no specific limit on K and, generally, there will be a K deficiency unless more K is added over that contained in sludge.

simplified application rate determination

Table XVIII-4 has been prepared to simplify the sludge application rate determination. This table shows application rates for various crops based on the nitrogen requirements, and assuming 70 lb organic nitrogen/ton of sludge, with a mineralization rate of 15-10-5, and an ammonium nitrogen content of 30 lb/ton of sludge.

TABLE XVIII-4. RATE DETERMINATION (tons/acre)

	Application yr				
	1	2	3	4	5
Crop*	Tons/acre of sludge				
Alfalfa	9.1	7.8	7.4	7.0	6.6
Orchard grass Clover grass	7.4	6.3	6.0	5.6	5.4
Corn (grain)	4.2	3.6	3.4	3.2	3.0
(stover)	1.7	1.5	1.4	1.3	1.2
Sorghum (grain)	3.0	2.5	2.4	2.2	2.1
(stover)	3.2	2.7	2.6	2.4	2.3
Corn silage	5.9	5.0	4.8	4.5	4.3
Oats (grain)	2.0	1.7	1.6	1.5	1.4
(straw)	0.86	0.74	0.70	0.66	0.62
Soybeans (grain)	6.0	5.1	4.8	4.6	4.3
(straw)	2.1	1.8	1.7	1.6	1.5
Wheat (grain)	3.6	3.0	2.9	2.7	2.6
(straw)	1.0	0.89	0.84	0.79	0.75
Barley (grain)	2.7	2.3	2.2	2.1	2.0
(straw)	1.0	0.84	0.80	0.75	0.71

*Same yields as in Table XVIII-1.

performance

This system should provide safe sludge disposal as well as providing nutrients for crop growth. In general, sludge application rates computed by nitrogen balance will result in adequate crop phosphorus but inadequate potassium.

STAFFING REQUIREMENTS

Staff requirements are shown on Table XVIII-5 (see following page). These requirements were based on the system having several disposal sites with sludge transported to each site by truck. The sludge is then transferred to the application truck. The labor does not include any farming operations, but includes application of sludge to the land.

TABLE XVIII-5. STAFF REQUIREMENTS

Description	Sludge quantity, tons/year			
	250	1,250	2,500	5,000
Truck drivers, number	2	2	4	8
Lab technicians, number	1*	1	2	2
Operator, number	1*	1	1	1

*Half-time

MONITORING

The monitoring program consists of the analyses shown in Table XVIII-6 (see following page). Sampling and monitoring must be performed by qualified personnel or outside laboratories.

Sensory Observations

Sensory observations can detect many problems before environmental monitoring tests. When injecting sludge, the application rate should be such that sludge does not surface. If sludge surfaces, the injector speed should be increased or the sludge flow decreased so that the quantity injected per unit area decreases. If the injector travel speed is excessive, soil may be thrown away from the shank creating an open trench.

If sludge is spread on the surface, the rate should be low enough to prevent excessive ponding or runoff. Excessive ponding is when the liquid is still above the surface several hours after application. Either excessive ponding or runoff indicates excessive application rates for the soil. This will vary widely from soil to soil.

NORMAL OPERATING PROCEDURES

Startup

The startup procedures include a daily check of trucks for oil level, fuel level, battery condition, radiator water level, lights, and turn signals. The injector(s) should be checked for flushing and lubrication after the previous use.

Solids content of the sludge should be determined in order to set the application rate. The total application rate should be determined and provided to operating personnel along with an application plan.

TABLE XVIII-6. MONITORING REQUIREMENTS

Sample	Test	Frequency
Sludge	TDS	Weekly
	COD	Weekly
	TKN	Weekly
	NH_3-N	Weekly
	NO_3-N	Weekly
	P	Weekly
	Fecal coliform	Monthly
	Fecal strep	Monthly
	Salmonella	Monthly
	Cysts	Monthly
	pH	Daily
	Cl	Monthly
	Alkalinity	Weekly
	Metals (Cd,Zn,Cu,Pb,Ni)	Monthly
	Na	Monthly
	K	Weekly
	B	Monthly
Soil	TKN	Annually
	NH_4-N	Annually
	P	Annually
	K	Annually
	Alkalinity	Annually
	Cation exchange capacity	Annually
	Salmonella	Annually
	Cysts	Annually
	Chloride	Annually
	B	Annually
	pH	Monthly
Wells, nearby streams	Coliform	Monthly
	Fecal coliform	Monthly
	NO_3-N	Monthly

If the sludge has a very high moisture content, the site may have to be covered more than once with rest periods between applications to prevent ponding.

Routine Applications

Sludge is transferred to the site(s) and applied according to the predetermined plan.

The operator should be alert for ponding or other signs of problems. A record of the application should be prepared as shown in Figure XVIII-3 (see following page). The operator

DATE ____________________

CROP ____________________ Number of Previous Years of Application _____

Required Sludge Loading Rate ____________tons/acre

Sludge Solids Concentration ______%.

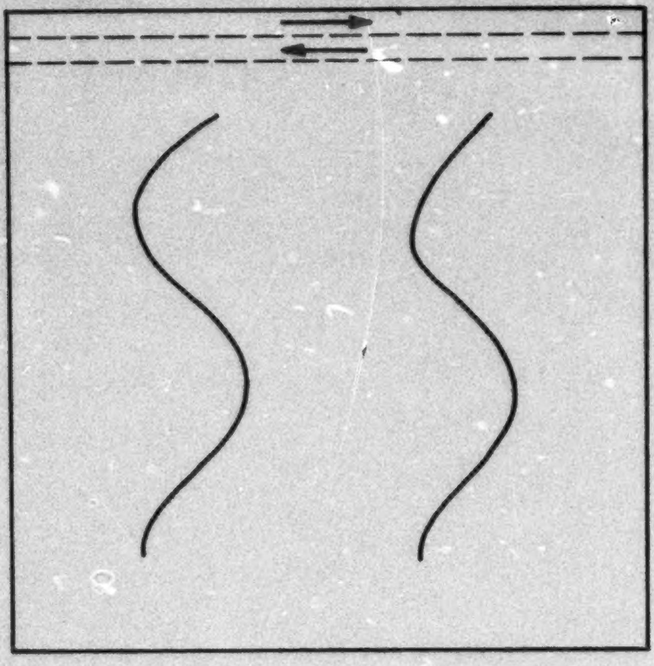

Figure XVIII-3. Site map record

should show the areas he has covered each day as well as the number of passes, and resulting application rate. These records will enable the farmer to determine additional fertilizer requirements, future application rates, and provide plant personnel with a record of the application.

Shutdown

At the end of the day the truck and applicator should be washed to remove any remaining solids and serviced. If the sludge was surface applied rather than injected, the farmer should be notified so that he can disc the area the following day in order to mix soil and sludge.

CONTROL CONSIDERATIONS

rate adjustment

Control of this process involves determination of application rate by close monitoring of sludge and soil conditions and determination of crop nutrient requirements. The operation may change substantially after each year of operation; for example, application rates may be lower each year due to residual nitrogen. The rate may be reduced after several years of application due to phosphorus or heavy metal buildup. Added to this variability is crop rotation which the farmer may practice.

Control steps required are proper rate setting, as described previously, and daily control of actual quantities applied. The actual application rate is varied by changing the number of passes made by the truck over the site. The field should be marked with numbered stakes to aid the equipment operators in proper application.

EMERGENCY OPERATING PROCEDURES

Loss of Power and/or Fuel

Loss of electrical power will not affect the field or transport operations. There will be an impact on the characteristics of the sludge. The nature of this impact depends on the type of processes involved. Most likely the solids content will decrease. Under these circumstances the solids concentration should be determined for each load of sludge. Nitrogen content and forms will change so the organic, NH_3^- and NO_3^- nitrogen should be checked for each load.

Adequate provisions must be made to pump sludge from the holding tank to the transport truck at the plant.

If the trucks are equipped with diesel engines and the fuel runs out, the entire fuel system must be bled to remove air prior to starting the engine.

Loss of Other Treatment Units

Other treatment units which will directly impact the land application operation are those required for stabilization and concentration or dewatering. If the stabilization process is not operating properly the sludge characteristics in terms of nitrogen forms and concentrations will change. If the concentration or dewatering process is not operating properly the sludge moisture content will be high and a greater volume must be handled. In either case, the sludge application rate must be changed to account for the change in the sludge characteristics.

TROUBLESHOOTING GUIDE

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
1. Crop suddenly dies or shows signs of poor health.	1a. Downward shift in soil pH.	1a. Soil pH should be maintained above 6.5, preferably 7.0.	1a. Add lime to soil.
	1b. (1) Excessive nitrogen application. (2) Insufficient nitrogen.	1b. Determine nitrogen applied and consult with agricultural extension service.	1b. (1) Reduce loading rate. (2) Increase loading rate.
	1c. Excessive heavy metal concentration.	1c. Heavy metal content of sludge and crop.	1c. Reduce loading rate or reduce heavy metal content through enforcement of pretreatment requirements.
	1d. (1) Excessive phosphorus application causing nutrient imbalance. (2) Insufficient phosphorus.	1d. Determine phosphorus application and consult with agricultural extension service.	1d. (1) Reduce application rate. (2) Add phosphorus.
	1e. Insufficient potassium.	1e. Determine potassium application and consult with agricultural extension service.	1e. Add potassium.
2. Surface runoff of sludge.	2a. Excessive application rate or poor soil percolation.		2a. Reduce application.
	2b. Ground saturated with rainfall.		2b. Discontinue application until soil has dried out.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
3. Aerosols drifting out of disposal area.	3a. Wind carrying aerosols.	3a. Visual signs of blowing or drifting mist.	3a. Discontinue spraying during windy periods. 3b. Convert spray nozzles to larger openings. 3c. Reduce spray pressure. 3d. Increase buffer area.
4. Trucks getting stuck in fields.	4a. Application of sludge during wet periods.	4a. Alternative application methods.	4a. Acquire a portable "rain gun" which can spray sludge over 200-300 ft diameter circle. 4b. Use large tires on trucks. 4c. Use tractor.
5. Mosquitoes breeding on site.	5a. Ponding of sludge.	5a. Stagnant ponds of sludge.	5a. Grade site to eliminate ponding, reduce application rate.
6. Leachate causing pollution of ground or surface waters.	6a. Excessive liquid application.	6a. Application rates and leachate quality.	6a. Intercept and treat leachate. 6b. Reduce liquid applied by improving sludge dewatering or reducing application rates.
7. Nitrate pollution of groundwater.	7a. Excessive nitrogen applications.	7a. Nitrogen application rates and nature of cover crops.	7a. Reduce application. 7b. Replace crop with one of higher nitrogen uptake.
8. Coverage of sludge in subsurface plow injection system not adequate.	8a. Plow is being pulled at excessive speed and soil is thrown away from shank.	8a. Plow speed.	8a. Pull plow at 1 mph or less.

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS
9. Drying of soil - sludge mixture is slow in subsurface injection system.	9a. Sludge being injected too deeply.	9a. Injection depth.	9a. Inject at 4 inches or less.
10. Plugging of subsurface injectors.	10a. Large sludge solids.	10a. Check sludge for large particles.	10a. Install sludge grinder.

COMMON DESIGN SHORTCOMINGS

Shortcoming	Solution
1. Farm operations can't take all of the sludge.	1a. Store sludge in lagoon.
	1b. Move to alternate disposal site.
2. Field too damp for injection, but not too wet to receive sludge.	2. Disconnect injectors and spray sludge on surface (monitor carefully).
3. Inadequate land acreage.	3a. Buy land, discontinue crop growth, and convert to dedicated land disposal site (higher application rates with no crops).
	3b. Change to crop with higher nitrogen utilization rate.
	3c. Dewater sludge and apply to surface.
	3d. Improve industrial pretreatment enforcement if land limitation is due to metals concentrations.
4. Inadequate transport and/or injector truck capacity.	4a. Purchase additional equipment.
	4b. Increase operating hours.
5. Inadequate storage capacity.	5a. Add storage lagoon.
	5b. Improve dewatering or concentration performance.

MAINTENANCE CONSIDERATIONS

Maintenance requirements are mainly cleaning and equipment service. The cleaning operation include daily flushing of the injectors and periodic flushing of the tanks. Truck and equipment preventative maintenance schedules will be specified in manufacturer's data.

SAFETY CONSIDERATIONS

Safety is related to vehicle and equipment operation. Generally, the highest potential for accidents is when equipment is being backed or trailers are being connected or disconnected from tractors. All drivers should be given a thorough drivers' training course including classroom and practice operation. All should be required to pass a driver's test specially designed for this operation.

The only safety measures necessary beyond the usual common sense is to require a spotter to assist drivers when backing trailers at the plant and to insure that truck tires are at adequate pressure and not excessively worn.

REFERENCE MATERIAL

References

1. Standard Methods for the Examination of Water and Wastewater.
American Public Health Association
1015 Eighteenth Street, N.W.
Washington, D.C. 20036

2. Knezek, B.D. and Miller, R.H. (ed.) Application of Sludges and Wastewaters on Agricultural Land: A Planning and Educational Guide, North Central Regional Research Publication 235, available through:
Cooperative Extension Service
The Ohio State University
1885 Neil Avenue
Columbus, Ohio 43210

Glossary of Terms and Sample Calculations

1. Sample Calculations to Determine Sludge Application Rates (taken from Reference #2).

Sludge: 2% NH_4-N, 0% NO_3-N, 5% total N, 2% P, 0.2% K
Zn, 10,000 ppm; Cu, 1,000 ppm; Ni, 50 ppm;
Pb, 5,000 ppm; Cd, 10 ppm

Soil: Silt loam, CEC = 20 meq/100 g; fertilizer recommendations from soil tests are 25 lb of P per acre and 100 lb of K per acre

Previous applications: 10 tons of sludge per acre for 2 previous years

Crop requirements (from Table XVIII-1):
180 bu corn requires 240 lb N, 44 lb P, and 199 lb K

A. Calculate annual rate based on N and Cd

(1) Available N in sludge

$2\% \ NH_4\text{-}N + 0\% \ NO_3\text{-}N = 2\%$ initially available nitrogen

5% total N - 2% = 3% organic nitrogen

Lb available N/ton sludge = 20 x 2% + 4 x 3%
= 40 + 12
= 52

52 lb available N/ton sludge

(2) Residual N (from Table XVIII-2) for 3% organic N

(a) Sludge added 1 year earlier
(available between first and second year)
(10 tons/acre)x(5.1 lb N/ton)= 51 lb N

(b) Sludge added 2 years earlier
(available between second and third year)
(10 tons/acre)x(2.3 lb N/ton)= 23 lb N

(c) Residual N = 74 lb

(3) Sludge Application Rate

(a) 240 lb needed - 74 lb residual = 166 lb from sludge

(b)
$$\frac{166 \text{ lb N}}{52 \text{ lb N/ton sludge}} = 3.2 \text{ tons/acre}$$

(c) Calculate application rate for 2 lb Cd/acre

$$\frac{2 \text{ lb Cd/acre}}{10 \text{ ppm CD} \times .002} = \text{tons/acre} = 100 \text{ tons/ac}$$

(4) The lower amount is applied = 3.2 tons sludge/ac

B. Calculate total sludge amount which may be applied (based on Table XVIII-3), maximum amounts are calculated as follows:

	Metal	Maximum amount, lb/acre	Conc. in sludge, ppm	Application rate, tons sludge/acre	Calculation
(a)	Pb	2,000	5,000	200	= $\frac{\text{2,000 lb Pb/acre}}{\text{5,000 ppm Pb x .002}}$
(b)	Zn	1,000	10,000	50	= $\frac{\text{1,000 lb Zn/acre}}{\text{10,000 ppm Zn x .002}}$
(c)	Cu	500	1,000	250	= $\frac{\text{500 lb Cu/acre}}{\text{1,000 ppm Cu x .002}}$
(d)	Ni	200	50	2,000	= $\frac{\text{200 lb Ni/acre}}{\text{50 ppm Ni x .002}}$
(e)	Cd	20	10	1,000	= $\frac{\text{20 lb Cd/acre}}{\text{10 ppm Cd x .002}}$

The lowest application rate is limited by Zn at 50 tons/acre.

C. Calculate P and K balances

(1) P
3.2 tons/acre x 2% P x 20 = 128 lb P/acre avail.
Recommendation is 25 lb P/acre.
No additional P needed

(2) K
3.2 tons/acre x 0.2% K x 20 = 12.8 lb K/acre available.
Recommendation is 100 lb K/acre.
K needed = 87.2 lb/acre

2. Application Rate - Field Measurement
The application rate determined for the particular application equipment.

3. Nitrogen Mineralization Rate is the rate at which organic nitrogen is converted to nitrate nitrogen. This is also referred to as decay rate.

4. Residual Nitrogen is the mineralized nitrogen remaining in the soil from previous sludge applications.

5. Pounds N/ton of sludge is determined by multiplying the percent N by 20.

6. meq/100 g (milliequivalents per 100 grams) is the standard measure for soil cation exchange capacity.

7. Olsen Bicarbonate Test - This test is outlined in Methods of Soil Analysis, Part 2, Published by American Society of Agronomy, 677 South Segoe Road, Madison, Wisconsin 53771, 1965, Page 1044.

XIX

LANDFILL

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PROCESS DESCRIPTION

process

The landfill operation and maintenance program described in this section applies to landfilling of dewatered sludge (15 to 20% solids). The example landfill system described consists of trenches filled with alternate layers of sludge and earth. Variations will be required for local constraints but the procedures described are applicable to any site.

operation

The dewatered sludge is transported to the site. The sludge is stockpiled or dumped directly into a 20-foot deep trench. A power shovel is used to place two-foot layers of sludge with one-foot intermediate layers of fill material. The final cover layer of fill is 3 to 5 feet. Figures XIX-1 and XIX-2 (see following pages) show a cross section and site plan, respectively, for this example landfill.

design differences

System modifications are made to compensate for certain climatic or soil characteristics. Equipment selection is based on site specific constraints. Transport to the landfill site may be accomplished by truck, rail, or barge. Pipelines may be used for liquid sludge transport with dewatering operations at the site. Trench depths and widths are variable. A wide, shallow trench may be excavated with a bulldozer and filled with a scraper. There are a large number of options available, but the basic system is the same.

leachate

The major concern for landfill operation is control of leachate so that groundwater supplies are not contaminated. Groundwater supplies are protected by careful site selection. A landfill must be located well above and/or away from any aquifers. An impervious layer should be located between the bottom of the fill and groundwater. When filling trenches, leachate water will often appear. This water should be pumped out to a tanker and returned to the treatment plant for treatment and disposal.

natural drainage

Natural drainage should be left undisturbed as much as possible. As shown on Figure XIX-2, fill trenches are arranged so that they are at least 30 feet from the drainage ditch. Farm tiles running through the site must be intercepted and routed to the nearest drainage ditch.

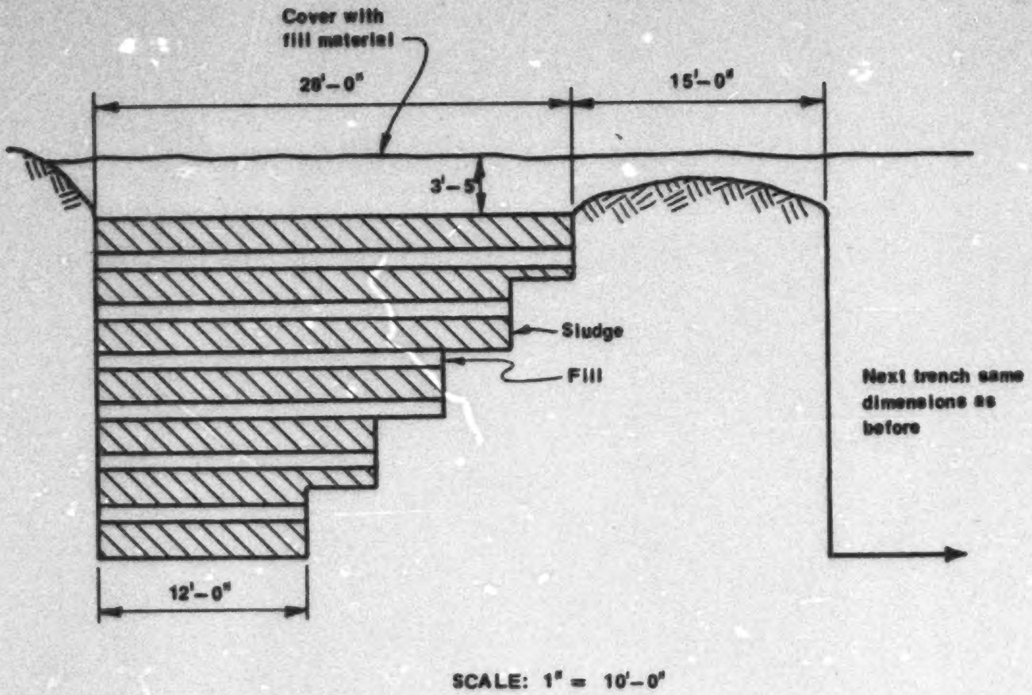
Cover with fill material
28'–0"
15'–0"
3'–5"
Sludge
Fill
Next trench same dimensions as before
12'–0"
SCALE: 1" = 10'–0"

Figure XIX-1. Landfill trench section.

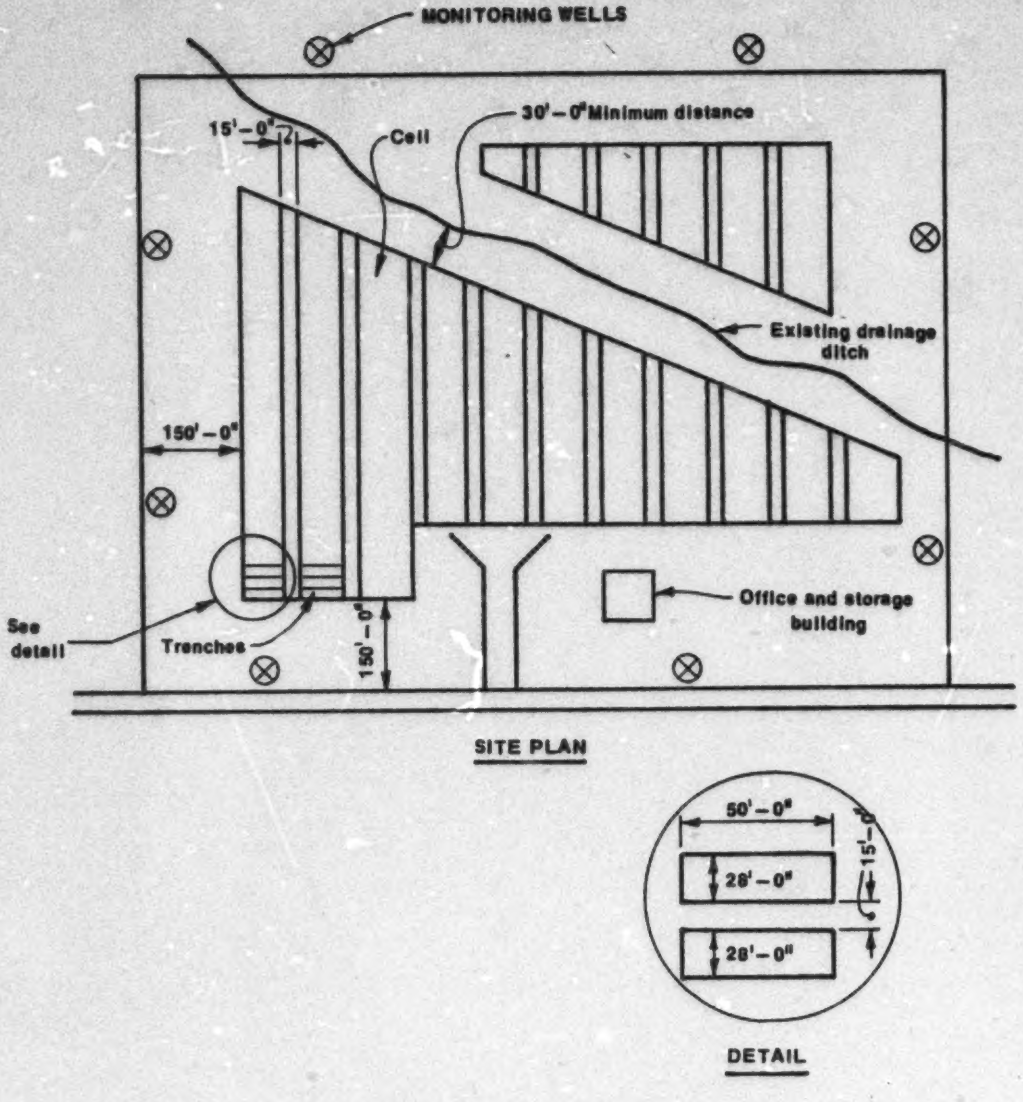
MONITORING WELLS
30'-0" Minimum distance
15'-0"
Cell
Existing drainage ditch
150'-0"
Office and storage building
See detail
Trenches
150'-0"
SITE PLAN
50'-0"
15'-0"
28'-0"
28'-0"
DETAIL

Figure XIX-2. Landfill site plan

TYPICAL DESIGN CRITERIA AND PERFORMANCE

Typical design criteria are shown on Table XIX-1. These criteria should be adjusted for local soil conditions. Sludge and fill layer depths should not be less than those values shown.

TABLE XIX-1. DESIGN CRITERIA

Trench width	
Bottom	12 ft
Top	28 ft
Trench length	50 ft
Sludge layer	2 ft
Intermediate fill layer	1 ft
Top fill cover	3-5 ft
Distance between trenches	15 ft
Distance between cells	15 ft
Distance from property line	150 ft
Distance from drainage ditch	30 ft

The proposed system can be operated such that no odors or vector habitats are produced. There is no runoff, and natural drainage is not interrupted. Leachate is controlled by not trenching to an elevation less than 15 to 20 feet above the impervious layer. Leachate quantity will be minimized by pumping excess from the trench to the tanker truck.

STAFFING REQUIREMENTS

Staffing requirements are shown on Table XIX-2. These requirements are shown for actual tonnage of sludge hauled to landfill (based on 30 mile roundtrip).

TABLE XIX-2. LANDFILL LABOR REQUIREMENTS

Sludge hauled	Labor, hr/yr		
tons/day (wet)	Operation	Maintenance	Total
5	2,800	1,200	4,000
25	5,200	2,080	7,280
50	10,400	4,160	14,560
100	20,800	8,320	29,120

MONITORING

There are eight monitoring wells located just inside the site boundaries (see Figure XIX-2). Each well is 30 feet deep. The wells consist of 6-inch PVC pipes fitted with a threaded cap on top and a well screen at the bottom. These pipes are placed in 16-inch borings, which are packed with 3/4 to 1-1/2-inch gravel. Sampling is accomplished through the use of a portable pump and a 20-foot, 4-inch PVC pipe with a foot valve at the bottom. These wells are sampled prior to startup of the landfill.

The drainage ditch should be monitored during flow periods. The ditch monitoring points are at the two points where the ditch crosses the site. The difference between the upstream and downstream locations will show if there is an increase due to the landfill operation.

Domestic wells less than 1/4 mile from the site should be monitored. Testing prior to landfilling provides background constituent levels.

Table XIX-3 shows a list of constituents to be included in the monitoring well and domestic well analysis.

TABLE XIX-3. WELL ANALYSIS

Boron
Cadmium
Copper
Iron
Lead
Mercury
Zinc

TDS
pH
Chloride
Phosphorus
NO_2-NO_3
Total coliform
Fecal coliform
Fecal streptococcus

Table XIX-4 shows the tests to be done on the drainage ditch flows.

TABLE XIX-4. DRAINAGE DITCH ANALYSIS

Fecal coliform
Coliform
Suspended solids
BOD

NO_3
NH_3
Phosphorus
pH

The monitoring wells are sampled monthly. The drainage ditch is sampled when rainfall occurs but no more than once per week. The domestic wells are sampled quarterly.

Sensory Observations

If proper visual observations are made, many potential problems can be avoided. Excessive odors and insect and vector habitats will result if sludge is not properly covered or leachate is allowed to stand in the trench. Visual observation of the sludge covering operation will show if sludge is properly covered at the end of each day.

Control of runoff to and from the site or trench is monitored primarily by visual means. Runoff due to rainfall should not be allowed to enter the site from neighboring property or conversely leave the site except through the drainage ditch. On-site runoff from rainfall should be prevented from entering a trench.

Completed landfill areas are seeded and should be observed to insure that grass distribution is adequate and that there are no exposed soil areas.

NORMAL OPERATING PROCEDURES

Startup

The trench site has been marked. The trench is excavated with material stockpiled nearby for later fill. The trench is protected from runoff by building a berm with some of the excavated material on three sides of the trench. The crane is then positioned for placing fill over sludge dumped into the trench.

Routine Operations

The end-dump trailers are backed up to the edge of the trench. After the sludge is dumped into the trench the power shovel is used to spread the sludge evenly along the bottom to a depth of two feet. The power shovel is used to sprinkle fill material over the sludge. If fill is dumped or bulldozed into the trench, sludge may be displaced rather than covered.

Shutdown

This operation is usually accomplished during daylight hours only. Every night when the operation is shutdown all sludge should be covered with fill material.

After the sludge is covered, a berm is built on the open side of the trench.

EMERGENCY OPERATING PROCEDURES

Emergency situations for the landfill operation are of a different nature than mechanical sludge treatment processes. Interruptions to normal operation are related to weather and soil condition related problems. Mechanical problems are related to vehicles rather than stationary equipment.

inclement weather

Although the site can be served by an all weather road, traffic adjacent to a trench may be impossible during heavy rainfall periods. If the rainfall period lasts longer than the period anticipated in design of the storage capacity (at the plant), then a temporary gravel road can be placed from the paved road to the trench being used. Covering the sludge will be more difficult but it can be done. If the crane is on tracks, it can be moved the relatively short distances required.

equipment failure

One standby tractor-trailer unit may be provided so that mechanical failure of one will not hinder hauling except the remaining units will be used for longer hours. Use of all trucks provides more capacity than necessary so that routine maintenance will not interfere with disposal operation.

The most critical piece of equipment is the crane used to fill the trench. However, filling can be accomplished with a dozer. Efficiency is somewhat reduced (more fill required due to displacement of sludge) but the sludge can be covered.

COMMON DESIGN SHORTCOMINGS

The most common design shortcoming is failure to detect an isolated area of permeable soil such as a sand lens. If, in the process of excavating a trench, some permeable soil is found, this area should be isolated by covering with at least 5 feet of clayey soil.

Another design shortcoming can be found in setting the slopes of the trench. If the slope is too steep, cave-ins are possible. Conversely, excessively low slopes result in inefficient trenching.

MAINTENANCE CONSIDERATIONS

Vehicle maintenance should include preventative maintenance in accordance with manufacturer's guidelines and daily inspection. The manufacturer's guidelines come with the equipment so will not be repeated here.

Daily inspection should include the following:

Fuel level
Oil level
Battery
Tires (or tracks)
Hydraulic systems (where applicable)
Grease crane and crawler.
Turn signals and brake lights on trucks

SAFETY CONSIDERATIONS

The safety considerations are listed below:

1. Maintain 5 feet from edge of trench and equipment (except for dumping or dozing into trench).
2. Provide traffic direction, especially spotter for backing trucks.
3. Provide fire extinguishers on all vehicles.
4. Provide equipment operation training sessions.

REFERENCE MATERIAL

References

1. Lukasik, G.D., and Cormack, J.W., "Development and Operation of a Sanitary Landfill for Sludge Disposal", paper presented at EPA 208 Seminar, Reston, Virginia, March 16, 1977.
   G. D. Lukasik
   Northshore Sanitary District
   301 West Washington Street
   Waukegan, Illinois 60085

2. Standard Methods for the Examination of Water and Wastewater.
   American Public Health Association
   1015 Eighteenth Street, N.W.
   Washington, D.C. 20036

Glossary of Terms and Sample Calculations

1. Lechate is the liquid remaining in the sludge which is usually high in BOD and suspended solids concentrations. This material will contaminate water supplies if not controlled.

2. Impermeable Soil usually consists of a clayey or hardpan soil or solid rock. Water will not pass through an impermeable soil layer.

3. Determination of Trench Capacity. First the trench volume is computed by multiplying the length by width by depth of each layer and summing the layer volumes. The trench capacity is determined by multiplying the sludge unit weight (65 lb/cu ft) by the trench volume. Using Table XIX-1 design criteria and Figure XIX-1, a sample calculation is shown below:

   The bottom layer contains 3 feet of sludge. The next layer contains 3 feet, the next - 2 feet, the next 3 feet, and the last layer has 3 feet.

   Volume, cu ft =
   (12 ft x 50 ft x 3 ft) + (16 x 50 x 3)
   + (20 x 50 x 2) + (24 x 50 x 3) + (28 x 50 x 3)

   Volume = 14,000 cu ft

   This volume is equivalent to the following sludge weight:

   Sludge Weight = 14,000 cu ft x 65 lb/cu ft
   Sludge Weight = 910,000 lb or 455 tons

4. Fill Time Period. For scheduling purposes, the capacity of each trench should be expressed as days of operation. This is determined by simply dividing the sludge weight capacity by the daily haul rate. Assuming 50 tons/day, the following fill time results:

   $$\text{Fill time, days} = \frac{455\ \text{tons}}{50\ \text{tons/day}} = 9.1\ \text{days}$$

   This means that a new trench must be prepared every 9 days.